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DECISION SCIENCE CONSORTIUM, INC.

A PERSONALIZED AND PRESCRIPTIVE DECISION AID

TECHNICAL REPORT 82-4

AD A118026

By

Marvin S. Cohen, Robert C. Bromage, James O. Chinnis, Jr.
John W. Payne, and Jacob W. Ulvila

Prepared for

Office of Naval Research

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July 1982

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the development of a computer-based display and analysis system which caters to the personal decision-making styles of users while hedging them about with safeguards against potential errors or biases. The general conceptual design brings together descriptive research in cognitive psychology on individual strategies in judgment and choice, and prescriptive theories which constrain optimal solutions while accommodating differences in judgment and ways of structuring the problem. A demonstration prototype aid, incorporating an advanced user interface, has been de-

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signed and partially implemented in a specific testbed and has sucessfully undergone a preliminary test with representative potential users.

The prototype aid design consists of a data base, a flexible general-purpose Planning Module, and four relatively specialized routines for customizing the aid. Portions of the data base, Planning Module, and Selection Module have been implemented in a demonstration attack planning system for the command staff of an attack submarine. The current system provides a relatively effortless user interface, consisting of high resolution color display, a joystick, and a single function key.

The design accommodates individual differences in beliefs, values, and preferred level of problem structure, in search organization and decision rule, and in features of "cognitive style" (number of options focused on, number of dimensions utilized, and time span of planning).

In addition, it offers substantial prescriptive support: Data and inferences are clearly separated, and sources of uncertainty indicated. Outputs of prescriptive models at any level may be directly displayed, at the user's request, based either on default values or on the user's own judgments. Finally, prescriptive prompts advise the user when information he has not observed seems to warrant attention.

A study of individual data-gathering and decision-making styles among submarine officers suggests that pronounced differences do exist to which a personalized aid might cater. A preliminary demonstration of the functioning prototype suggests that it will cater effectively and acceptably to those differences.

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SUMMARY

This report describes the development of a computer-based display and analysis system which caters to the personal decision-making styles of users while hedging them about with safeguards against potential errors or biases. The general conceptual design brings together descriptive research in cognitive psychology on individual strategies in judgment and choice, and prescriptive theories which constrain optimal solutions while accommodating differences in judgment and ways of structuring the problem. A demonstration prototype aid, incorporating an advanced user interface, has been designed and partially implemented in a specific testbed and has successfully undergone a preliminary test with representative potential users.

The prototype aid design consists of a data base, a flexible general-purpose Planning Module, and four relatively specialized routines for customizing the aid. Portions of the data base, Planning Module, and Selection Module have been implemented in a demonstration attack planning system for the command staff of an attack submarine. The current system provides a relatively effortless user interface, consisting of high resolution color display, a joystick, and a single function key.

The data base consists of basic inputs (in the submarine testbed these concern own ship, contacts, and the environment) together with a set of prescriptive models which aggregate those inputs into higher level inferences and forecasts.

The Planning Module serves, first of all, as an extremely versatile tool for interacting directly with the data base and for evaluating alternative actions. It enables the user to sample information from any preferred level of aggregation in the data base, organize his search for information efficiently in terms of either action alternatives or evaluative criteria, and vary

the number of alternatives examined, the amount of information requested concerning each, and the time into the future which planning encompasses. Moreover, this module clearly distinguishes conclusions from evidence, and indicates the sources from which each inference is derived.

The Selection Module (which has also been implemented) allows the user to personally select the portion of a large data base which will be immediately accessible through the Planning Module. The user can then efficiently search the data base in the prechosen order. At the same time, because of its streamlined interface, the Selection Module permits him to alter his prioritization and retrieve any other information quickly and easily.

The Adjust Module will enable the user to insert subjective judgments in place of default values at any level in the data base. The Planning Module will then display the implications of the hypothetical or revised values for any higher level inference. (Default values, however, would continue to be stored and displayed.) The Adjust Module thus accommodates individual differences in beliefs and preferences and - from a prescriptive point of view - adds a potentially valuable source of information (the user) to the data base.

The Alert Module facilitates individual heuristic strategies which evaluate actions by reference to cutoffs (as opposed to tradeoffs). The user can set a cutoff or threshold for any variable in the data base (at any level of aggregation). The Planning Module will forecast whether or not the threshold is expected to be crossed for any given action alternative, and if so, when. It also alerts a user, whose attention may be otherwise engaged, when cutoffs are crossed.

Advisory prompts, in the Planning Module, monitor information not requested by the user, and advise him when that information

appears to have prescriptive implications different from the information he has observed. This function will enable the user to concentrate his own attention selectively, in areas he regards as critical, while notifying him when other issues seem worthy of attention. In the Advisory Module, the user sets his own "tolerance" for disconfirming information, thus determining the nature and frequency of advisory prompts.

A study of individual data-gathering and decision-making styles among submarine officers suggests that pronounced differences do exist to which a personalized aid might cater: e.g., in level of aggregation of preferred information, number of evaluative dimensions used, employment of cutoff criteria, attitudes toward risk, and patterns of information search. Finally, a preliminary demonstration of the functioning prototype suggests that it will cater effectively and acceptably to those differences.

1.0 INTRODUCTION

1.1 Computers as Aids to Thought

By interacting with machines, humans increase their capacity not only to sense the environment and act upon it, but also to think. Guidelines for the human factors engineering of the man-machine interface have traditionally focused on sensing and acting: i.e., display features and control configurations that conform to human capabilities and predilections. As computers take on expanded operational roles, however, attention has begun to turn to machine-assisted thought, and to the manner in which computer-implemented storage, retrieval, and manipulation of data can be optimally interfaced with human cognitive structures and processes.

This problem tends to arise wherever information systems are introduced into non-routine "management level" tasks: e.g., in military command and control and in governmental or business planning. Computers have often produced controversy; in some cases there has been severe organizational and institutional resistance (e.g., Miller, 1980; Sinaiko, 1977; Beard, 1977; Swanson, 1974). Among the causes of such resistance, the chief one, perhaps, is not display and keyboard design, but the mismatch between an intended user's problem-solving or decision-making style and that rigidly imposed on him by the computer.

Recent developments in computer science and in cognitive psychology, if taken together, provide a basis for the design of a personalized information processing interface. Within computer science there have been impressive technical advances in hardware and architecture, display technology, programming languages, data base structures, and query techniques (e.g., Nilsson, 1980; Allen, 1978; Bolt, 1979). These make possible, _in_

principle, a high degree of customization of man-computer interactions to the individual user's needs. In psychology there is a long-standing research tradition on individual differences in abilities thought to comprise intelligence. Recently, however, cognitive psychologists have turned to the investigation of how people differ in their actual performance of cognitive tasks (e.g., Newell and Simon, 1972; Kahneman, Slovic, and Tversky, 1982; Payne, 1982). From such performance, hypotheses are formulated about differences in the internal structures people use to encode knowledge and in the strategies they adopt for obtaining and processing it.

Unfortunately, little progress has been made as yet in fusing these two trends. One reason, perhaps, is that in the effort to personalize the interface for machine-assisted thought, two objectives can easily conflict: On the one hand, we want to cater to the preferences of the user, whatever they may be; on the other hand, we want to help him avoid the errors or biases to which his approach might give rise. What are needed are aids which are personalized and (simultaneously) prescriptive; they must, somehow, bring to bear findings and methods not only in human factors engineering, computer science, and cognitive psychology, but also the prescriptive theory of decision making.

A healthy sense of cooperation between person and prescriptive model may be fostered by recognition of their complementary limitations. Decision makers are, in many contexts, confronted by an increasingly unmanageable volume of information - generated, in part, by the success of the computer in taking over more routine data management chores (and also due, in military settings, to the increased range and variety of sensors, weapons, and communication channels). Decision-making strategies tend to be even more idiosyncratic, and less normative, under information overload (e.g., Payne, 1976; Streufert and Streufert, 1981b); but a secondary effect is that decision makers in

many fields have become more interested in prescriptive aids which help them integrate large quantities of information.

At the same time, there is a growing sense of the limitations of modeling (e.g., Watson, Brown, and Lindley, 1977; Keeney, 1982). Since "objective" methods can seldom address more than part of a complex problem, prescriptive aids are appropriately regarded not as "know-it-alls" but as fallible "advisors" (Patterson et al., 1981). Eliminating the human from the process (besides incurring resistance) often represents a serious underutilization of available cognitive resources (cf., Cohen, 1982; Ramsey and Atwood, 1979).

1.2 Overview

The present report describes the development of a prototype aid which is both personalized and prescriptive. It attempts to balance two objectives: (1) to allow maximal user flexibility in selecting information for display and in customizing the aid interface according to his own needs; (2) to help the user organize and evaluate the implications of displayed information for the problem at hand. An essential feature of the aid is that the user decides precisely how much, and what kind of, prescriptive advice he will get.

The prototype aid has been designed and partially implemented for a specific operational context: approach and attack planning by the Command staff of a nuclear attack submarine. However, only the data base of the aid is affected by the nature of the specific application. Its functional logic, and the methods used to achieve both personalization and prescriptive impact, are quite general. The implementation of a demonstration prototype system in a specific context, however, permits a realistic test of the feasibility of the concepts, with potential users.

Our strategy in aid design has been neither wholly "top-down" nor wholly "bottom-up." User preferences have played a critical role both at the start and throughout. The perceived needs and performance patterns of submarine Command Staff members were gathered initially through informal discussions with active or recently retired personnel, through observation of training exercises and videotapes, and through a formal questionnaire (Appendix C). After the implementation of an initial functioning prototype, interaction with the aid was observed, feedback elicited, and - as a result - specific design changes made.

At the same time, we have adopted the hypothesis that there are important current findings in cognitive psychology (about how people solve problems) and in prescriptive theory (about constraints defining optimal methods) that ought to be taken into account in the design process. If these applications bear fruit, the potential is for an aid that is finely tuned to human patterns of information processing and capable of gently pointing the way around likely dangers and pitfalls.

Section 2.0 sketches the technical background in prescriptive theory and psychology which we have drawn upon in designing the aid. The functional logic of the aid is presented in general terms in Section 3.0. Section 4.0 introduces the operational setting, submarine approach and attack, which has served as the testbed for prototype development; and the prototype itself is described in Section 5.0. Section 6.0 describes a preliminary demonstration of the aid with former submarine commanding officers. Conclusions regarding the feasibility of the approach and possible directions for further development are presented in Section 7.0.

Earlier work on the attack planning problem may be found in Cohen and Brown (1981) and Cohen (1982).

2.0 DECISION MAKERS, DECISION PROCESSES, AND PERSONALIZED AIDS

How are the users of decision aids likely to differ in their approaches to decision making and problem solving? What are the consequences of such differences for success in task performance? And how should aids be personalized so as to enhance both user acceptability and quality of performance?

We consider, briefly, two general ways in which decision makers have been thought to differ from one another:

- in the parameters and structure of a prescriptive model based on their personal beliefs and preferences; and
- in the heuristic strategies, decision processes, and cognitive styles which they adopt in problem-solving.

The interplay of findings from these areas helps define the potentialities and limitations of personalized decision aiding.

2.1 Individual Prescriptive Decision Models

Ironically, a driving force in the evolution of prescriptive theories of decision making has been the need to accommodate individual differences. An objective rule for betting in games of chance, maximization of expected value, applies only where probabilities of outcomes can be mathematically defined (as in rolling dice) and where the desirability of outcomes is physically measurable (e.g., by money). Generalizations of this basic rule to situations where those conditions do not hold have led to the modern technique of decision analysis (cf., Edwards, 1954, 1961; Raiffa, 1968; Brown, Kau, and Peterson, 1974). Von Neuman and Morgenstern (1947) formalized the notion of a subjective dimension of value, i.e., utility, and extended it to in-

dividual preferences among probabilistic states of affairs. De Finetti (1937/1964) and Savage (1954) developed formal systems for the quantification of an individual's "degree of belief," or subjective probability, about uncertain propositions, and developed axiomatic justifications for the merging of utilities and subjective probabilities into a new prescriptive rule, maximization of subjectively expected utility (see Appendix B). More recently, rigorous techniques have been developed for combining subjective preferences with respect to individual components of value into a single multiattribute utility measure (e.g., Keeney and Raiffa, 1976).

The prescriptive force of decision analysis, in this form, is not to dictate to an individual in any absolute sense what he "ought" to do or believe. Rather, it indicates what choices and beliefs are logically consistent with other preferences and beliefs which he chooses to accept (cf., French, 1979).

2.1.1 Implications for personalized aids. These elements of personalization are by no means shared by all prescriptive approaches. Techniques in operations research (e.g., cost/benefit analysis) commonly purport to be "objective" and "value free" (Watson, 1981). The approach to decision analysis adopted above, however, has two important implications for personalized aids:

(1) Decision-analytic aids do not address only the part of a problem that can be objectively measured. Actual decisions nearly always involve a number of "soft factors" (e.g., uncertainty about the intentions of a business competitor or of a military foe; the relative importance of different objectives, like money and prestige). The decision maker's own experience may be the only source of relevant information in these matters, while an exclusively "factual" approach could be fatally incomplete. Aids

which combine subjective and objective inputs must accommodate individual differences among users in assessments of uncertain states of affairs, attitudes toward risk, and tradeoffs among competing objectives.

(2) The second point is equally important, though far less widely recognized. Just as it does not prescribe inputs, decision theory constrains, but does not dictate problem structure. Typically, there is more than one way to express the probability of a hypothesis in terms of probabilities for other propositions; and there are multiple decompositions of the utility of an option into preferences for separate attributes. A good structure for a particular decision maker breaks the problem down into components about which that decision maker has either objective data or personal experience. Individuals might benefit differently from different analyses of the same problem.

In particular, it has been suggested that experts differ from novices in their capability to individually recognize a very large number of different problem situations (De Groot, 1965; Chase and Simon, 1973). Klein (1980) argues that experts tend to reason holistically, by analogy with previous similar experiences, rather than by explicit analysis and computation. Klein warns that imposition of analytical models may actually impair expert performance. In terms of decision theory, however, this distinction between experts and novices is accommodated by the notion of personalized problem structures. The expert might produce quite creditable holistic judgments of problem components which he has "seen before" but which a less experienced individual would need to analyze into more familiar elements. (Nonetheless, experts too are subject to error - particularly when a problem which appears familiar has novel aspects; cf., Sage, 1981. Experts may benefit from analysis of such novel components.) The implication is that if decision aids are to

exploit the capabilities of each potential user, a variety of models, with different functions and at different levels of aggregation, should be made available (cf., Strub and Levit, 1974).

2.2 Individual Strategies in Inference and Choice

Prescriptive decision theory does not provide a description of actual performance, either in probabilistic reasoning or in the evaluation of actions (cf., Einhorn and Hogarth, 1981). Recent research in cognitive psychology has shed light on the internal processes and structures which people employ in such tasks, and how they differ.

2.2.1 Choice. One line of research has explored the strategies people use in choosing among actions. Prescriptive theory requires that a single score for each option (its expected utility) be derived, which integrates all the available information about that option: i.e., its score on each of a set of attributes, or the probabilities and utilities of its possible outcomes. Several descriptive models of choice behavior have been proposed, however, which involve more partial samplings of the available data (e.g., Payne, 1973; Svenson, 1979).

In Tversky's (1972) Elimination-by-Aspects (EBA), for example, the decision maker sequentially considers attributes characterizing decision options; the order of consideration is probabilistically related to their relative importance to the decision maker. Once an attribute is selected, a threshold is established, and all options are eliminated that do not score at or above the threshold on that attribute. A new attribute is then selected from those remaining, and the process is continued until one option is left. In another decision strategy, called "satisficing" (Simon, 1957; Svenson, 1979), the decision maker adopts a conjunctive criterion involving cutoffs on one or more

dimensions. He then compares successive options to the criterion until he finds one that is acceptable, whereupon he stops.

In each of these examples, an option stands a chance of being eliminated for falling below a cutoff, even though it scores high on other attributes. EBA and satisficing do not allow consideration of tradeoffs across different dimensions of value.

Different decision rules have different implications for the order in which people elect to receive information (Payne, 1973, 1976). Some strategies imply a search organized by options, others a search organized by attributes. For example, the prescriptive model and satisficing suggest that each option will be evaluated before information concerning the next option is requested. EBA, on the other hand, implies that areas of evaluative concern are fully dealt with in turn.

Individual decision makers vary in the decision strategies which are reflected in their information-seeking behavior and in their verbal protocols (Payne, 1976; Russo and Dosher, 1981). But little work has been done to discover whether these individual differences are consistent across time and tasks (Svenson, 1979); instead, emphasis has been on the role of task variables. For example, when there are a large number of choice options, decision makers tend to select routines like EBA which quickly eliminate some options by more approximate methods. They may then switch over to routines which integrate all the available information about the remaining options (Payne, 1976; Wright and Barbour, 1977).

A small but important body of research concerns the likely impact of non-optimal heuristic strategies on the quality of the judgment or decision. In many situations, the cost of using approximate methods may not be too great, while savings in time and effort may be substantial (Thorngate, 1980; Russo and

Dosher, 1981). However, work by von Winterfeldt and Edwards (1973, 1975) suggests that large losses can in principle occur when available information is not used.

2.2.2 Inference. A different body of research (e.g., Kahneman, Slovic, and Tversky, 1982) has explored distortions to which human concepts of uncertainty may be subject. For example, the probability of an event may be judged by the ease with which "scenarios" containing the event can be mentally called to mind, leading to idiosyncratic biases based on variations in individual experience (Tversky and Kahneman, 1974; cf., Gettys, Kelly, and Peterson, 1973). More fundamentally, individuals vary in their tendency to think about uncertainty in a probabilistic way, rather than in a black-and-white fashion (Wright and Phillips, 1976).

A number of studies show that people consistently overestimate their degree of certainty, even in areas where they are (rightfully) regarded as experts. Experts on the other hand, appear to be less overconfident than novices (Oskamp, 1965; Lichtenstein, Fischhoff, and Phillips, 1982). People often do not sufficiently consider the imperfect credibility of an information source - i.e., they proceed as if information reported to them were known to be true rather than merely reported (Schum, DuCharme, and DePitts, 1973). In addition, people may ignore evidence that contradicts a previous datum, or double count redundant evidence (Schum and Martin, 1981). Patterns of information search often focus on data that cannot fail to confirm a favored hypothesis, rather than on data which might test it (Wason, 1960, 1968; Einhorn, 1980).

2.2.3 Cognitive style. Cognitive style has been regarded as a relatively invariant, abstract feature of a decision maker's approach to information across a variety of tasks (cf., Sage,

1981; Libby and Lewis, 1977). Perhaps the most common differentiation made in this literature is represented by a related cluster of distinctions between "analytic" and "heuristic" (Huysman, 1970; Mock, Estrin, and Vasarhelyi, 1972), "abstract" and "concrete" (Schroder, Driver, and Streufert, 1967; Sage, 1981), "systematic" and "intuitive" (Bariff and Lusk, 1977; McKenney and Keen, 1974), and "scientific" and "managerial" decision makers. The common thread is a distinction between preference for formal, explicit analysis, breaking a problem down into elements, and an approach based on global intuition, trial and error, or "common sense."

Unfortunately, there is little evidence establishing a relationship between these categories (based on self-descriptions) and actual information-seeking behavior (Zmud, 1978; Keen, undated). It has been found that systematics generally take more time and do better in decision problems than heuristics (e.g., Mock et al., 1972). Other results, however, have been inconsistent: showing that systematics prefer more information or less information and prefer either aggregated or raw data as compared to heuristics (cf., Libby and Lewis, 1977; Zmud, 1978). McKenney (quoted in Mock et al., 1972) states that the propensity to be analytical increases with task familiarity; Klein (1980) and Sage (1981) suggest that experts will be more intuitive.

A second problem in this literature is the failure to validate the claim that cognitive styles are task invariant. Studies which have attempted to do so have produced disappointing results (cf., Libby and Lewis, 1977), and recent reviews (Libby and Lewis, 1977; Sage, 1981) have shifted emphasis toward the influence of task features on decision styles adopted by the same individual at different times.

In a few cases, "cognitive styles" have been defined in relation to actual cognitive behavior. Thus, Driver and Mock (1976) defined four styles by reference to two fairly specific processing dimensions: amount of information used and degree of focus. The latter refers to a tendency to consider only one solution, model, or option versus a tendency to entertain multiple possibilities. Streufert and Streufert (1981a) present criteria for "integrative" decision-making styles in terms of the number of, and length of time between, information requests and decisions based upon them. Streufert and Streufert (1981b) report that integrative decision making decreases with decision urgency, but is an inverted-U-shaped function of the amount of information available.

2.2.4 Implications for a personalized aid. Descriptive work on human inference and and decision processes has implications for both the personal and prescriptive aspects of decision aiding.

2.2.4.1 Personalization and efficient flexibility. "Flexibility" in and of itself is not a sufficient objective in system design. It is possible to make each of a vast number of logically possible information acquisition strategies equally easy, by allowing the user to indicate what he wants item-by-item. But such a system does not really facilitate the selection of strategies as such; to deal explicitly with all possible search orders would be beyond the time and capabilities of both user and device. The objective of personalization is to delimit the subset of strategies which an individual is most likely to prefer. Decision aids may then be tuned to facilitate explicit selection from this smaller group of strategies, while still affording the general "flexibility" of an arbitrary item-by-item search sequence. Such aids are efficiently flexible in their responsiveness to likely user needs.

The most natural way to acquire and process information can vary as a function of the individual and the task. Several such

forms of variation seem to occur frequently enough in performance to justify an aid design which facilitates their employment:

- search organized by options or by attributes,
- decision rules based on cutoffs or tradeoffs,
- level of aggregation of information.

In addition, it seems desirable that an aid facilitate differences involving:

- focus on one or many options,
- desired amount of information, and
- time into the future over which planning takes place.

There is little evidence that particular individuals are consistent across tasks in these preferences, and some indication that they are not. In the case of gross categories like "intuitive" and "analytic," moreover, there is no reliable mapping of traits onto system design features and certainly no indication of how different traits interact (cf., Huber, 1982).

2.2.4.2 Prescriptive prompting. - An important factor in designing a personalized and prescriptive aid is the impact of individual preferences on performance quality. Simplifying for illustrative purposes, alternative strategies (A and B) for performing the same task may fall into one of two classes in this respect:

- Strategy A is generally expected to be more accurate or yield higher payoffs than strategy B, but requires more training, more time, and/or draws away more attention from other tasks.

An example in the area of choice might be evaluating each option by reference to all the relevant dimensions (A) versus eliminating some options by reference to only a few (B). In the area of inference, it is often difficult to assess the overall credibility of a conclusion based on several steps of reasoning (A); one can simplify by ignoring the uncertainty at early stages (B). In these cases, differences among people in preference between A and B might reflect differences in their underlying ability to perform A, in their training or knowledge, in their handling of workload, in degree of motivation, or in their evaluation of the cost of errors.

- For some people, strategy A is expected to be more effective (better in accuracy, payoffs, speed, effort, etc.) than strategy B, while for other people, strategy B is more effective than A.

An example might be search organized by options versus search organized by attributes. Payne (1981) speculates that these types of search reflect individual differences in the way knowledge is internally represented. Similarly, people who differ in their degree of experience or areas of expertise may prefer different ways of structuring a problem.

These distinctions have implications for the appropriateness of prescriptive advice in a personalized decision aid. In the second case discussed above, the user usually does best with the strategy which he prefers; accordingly, an interactive system should simply facilitate selection by the user of the information processing rule or structure to be employed.

In the first case the computer's role may, at the request of the user, be somewhat more active. It involves a conflict between the user-preferred and the normative strategy - though the use of the former may be well justified by savings in time and

effort. In such cases, the computer can assist by applying a prescriptive model to the problem, in parallel with the user's own effort which it monitors. The aid may then advise the user when discrepancies seem significant. The prescriptive model applied by the aid, of course, has no automatic claim to truth; it takes the role, rather, of a "cooperative adversary" or "devil's advocate." It enables the user to concentrate his own attention selectively, in areas that he regards as critical, while notifying him when other issues seem worthy of attention. The degree of discrepancy which justifies a prompt might be set by the user himself, reflecting his own informal assessment of the value of his time and effort relative to the cost of errors.

Advisory prompts of this sort might signal a user who is employing cutoff criteria that tradeoffs bear looking into. More generally, the user would be advised when information which he has not examined may have implications that clash with information that he has examined.

A variety of prompts or other aid features might facilitate probabilistic reasoning:

- inferences should be clearly distinguished from data;
- all sources of uncertainty in a chain of reasoning should be clearly specified;
- when a decision depends on the probability of an event, the aid might prompt the user with possible scenarios in which the event could occur.

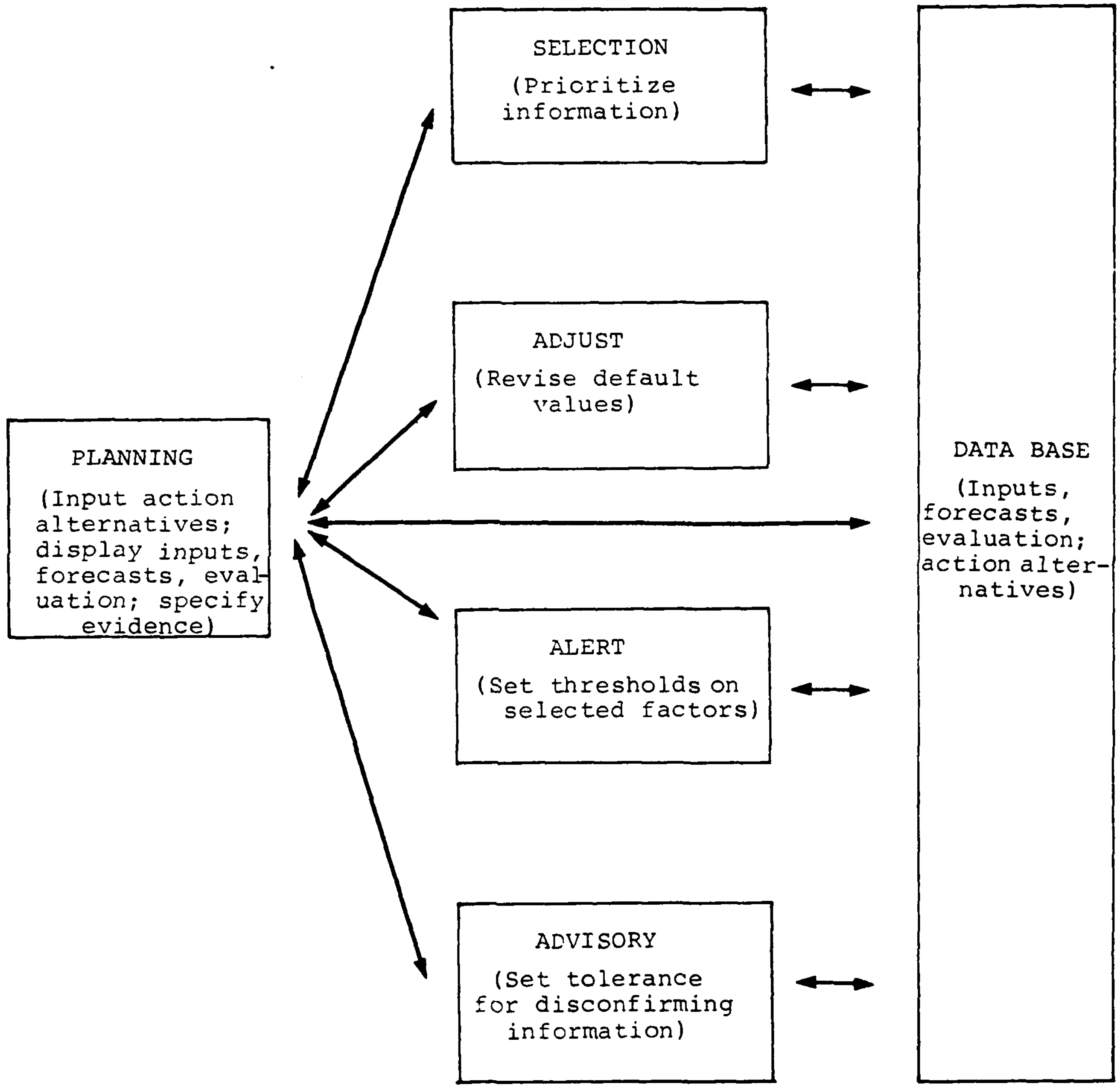
3.0 A PROTOTYPE AID: GENERAL CONCEPT

We have identified a set of individual differences in cognitive performance which it would be desireable to facilitate in a personalized aid, and a corresponding set of biases or errors which prescriptive features of the aid might help prevent. In the present section, we describe the conceptual requirements or functional design, of a decision aid which incorporates these features. The description (outlined in Figure 3-1) will be on a quite general level, intended to represent a framework within which actual aids, addressing specific sets of users and problem contexts, might be developed. The only constraint on such problems is that they involve choices among options characterized by multiple uncertainties and/or competing objectives, and that there be sufficient time and opportunity to consult a decision aid. One such specific aid has been designed and partially implemented and is described in Section 5.0

3.1 Data Base

A major function of the aid is to facilitate the management of a large, and possibly changing, data base. Such a data base will contain information at a number of levels of aggregation. At the most basic level are the inputs to the aid. These may be either variables (i.e., periodically updated results of new observations) or facts (i.e., prestored or relatively unchanging information). Inputs, although they are "raw data" with respect to the aid, may represent a considerable degree of prior analysis: e.g., inputs to an aid at one level in an organization may be the outputs of analysis at a lower level. (In general, however, such inputs will not be taken at face value; rather, the aid assists the user in assessing their credibility.)

Figure 3-1. Structure of Prototype Aid



A second element in the data base is a prescriptive model, or set of prescriptive models, which enables it to aggregate inputs into higher level inferences and forecasts: e.g., reports of unit status may be integrated into an assessment of overall organizational capability. If the user wishes to evaluate action alternatives, the data base stores the alternatives he chooses to consider and uses them to derive action-contingent forecasts.

Finally, the data base model integrates all the information about each action alternative into a single evaluative measure based on probabilistic forecasts and assessments of the values of possible outcomes.

3.2 Planning Module

The heart of the aid is the Planning Module. It serves, first of all, as an extremely flexible and powerful tool for interacting directly with the data base. In particular, at the user's request, it:

- displays basic inputs;
- displays inferences and forecasts derived from input data and prescriptive models;
- specifies the evidence upon which any inference or forecast is based;
- accepts hypothetical action alternatives from the user and displays forecasts contingent on specific options;
- prioritizes actions either with respect to specific subgoals, or with respect to an overall figure of merit.

The design of the Planning Module has been tailored to accommodate individual differences among users both in the information they select for review and in the way they select it:

- The degree of analysis and problem structuring is up to the user: displayed information can be at any level of aggregation (from raw data to forecasts of critical events to action evaluations).
- The user can efficiently organize his information search around actions (e.g., requesting forecasts of a number of events contingent on a given option) or around evaluative dimensions (e.g., exploring how a number of different actions affect the forecast of a given event.
- The user can focus on one (or a few) options or scan a large number superficially.
- The user can explore the evidence for a particular inference or forecast in depth, or he can review a large number of relatively independent inferences and forecasts.
- Action alternatives considered by the user may extend longer or shorter periods of time into the future.

3.3 Customizing Modules

In addition to this direct, flexible use of the Planning Module, the user can, if he wishes, specifically customize his interaction with the data base. He can personally modify the Planning Module in four different ways (Figure 3-1):

- By means of the Selection Module, the user can prioritize data base elements. Then, in the Planning mode, he can search the data base quickly in the prechosen order.
- In the Adjust mode, the user can insert subjective judgments in place of default values at any level in the data base. The Planning Module will then display the implications of the hypothetical or revised values for any higher level inference. (Default values, however, continue to be stored and displayed.)
- In the Alert Module, the user can set a cutoff or threshold for any variable in the data base (at any level of aggregation). The Planning Module will forecast whether or not the threshold is expected to be crossed for any given action alternative, and if so, when. At the time when the threshold is in fact crossed, the user is alerted.

* Advisory prompts, in the Planning mode, monitor information not requested by the user, and advise him when that information appears to have implications different from the information he has observed. In the Advisory Module, the user can set his own "tolerance" for disconfirming information, thus determining the nature and frequency of advisory prompts.

3.4 Summary

The basic conceptual design outlined above accommodates individual differences in beliefs, values, and preferred level of problem structure (Section 2.1), in search organization and decision rule (Section 2.2.1), and in features of "cognitive style" (number of options focused on, number of dimensions utilized, time span of planning; Section 2.2.3).

In addition, it offers substantial prescriptive support: Data and inferences are clearly separated, and sources of uncertainty indicated (Section 2.2.2). Outputs of prescriptive models at any level may be directly displayed, at the user's request, based either on default values or on the user's own judgments. Finally, prescriptive prompts advise the user when information he has not observed seems to warrent attention.

A more detailed design for each portion of the prototype aid, as described above, will be presented in the particular context of submarine approach and attack. Parts of the Planning Module, Selection Module, and Data Base have been implemented in a demonstration prototype system.

4.0 SUBMARINE APPROACH AND ATTACK

4.1 The Decision Setting

A specific context selected for development of a prototype aid is attack submarine-based antisubmarine warfare (ASW). The dilemmas faced in approaching and attacking a hostile submarine are, however, characteristic of many situations involving stealth in warfare: How long should I attempt to remain undetected and to improve my position, before I tip my hand by launching a weapon?

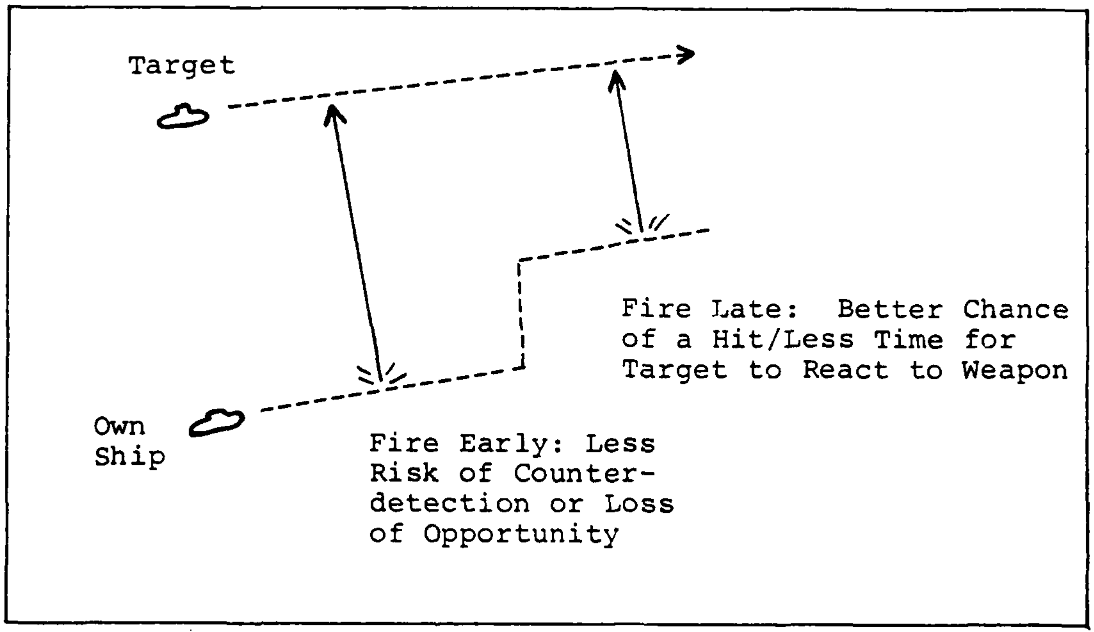
Some of the tradeoffs involved are outlined in Figure 4-1. On the one hand, if own ship fires later and closer to the target, the attack, if it occurs, is more likely to succeed: first, because the accuracy of target location and motion estimates will be improved, hence also the chance of a hit; second, because the target will have less time to respond (either by evading the weapon or counterattacking) when it hears the weapon in the water. On the other hand, the longer own ship waits, the greater the chance it will be counterdetected <u>before</u> attack, losing the advantage of surprise; or that the opportunity to attack will simply slip away, either by loss of contact or arrival of the target in a less favorable region. In all these considerations, the Commander must balance the objectives of preserving own ship against the objective of destroying the target.

In fact, time of fire is not the only decision in approach and attack which involves uncertainty about outcomes and competing objectives: the CO must decide, for example, whether to attack at all, and if so, against what targets, with what weapons, and after what maneuvers. In all these choices, like time of fire, tradeoffs occur: in target selection, where hostile platforms may vary in importance and in threat to own ship; in weapon se-

Figure 4-1.

Passive Approach and Attack:

Time of Fire Decision Tradeoffs Among
Range-Related Opportunities and Risks



lection, where cost or supply may be correlated with effectiveness; and in selecting among maneuvers that may optimize target localization only by exposing own ship to counterdetection. In all these choices, the CO has a limited amount of time and a very large quantity of data: pertaining to the threat or threats (target classification, location, motion, weapon and sensor capabilities, and intentions), own ship (weapon and sensor capabilities, targeting priorities), and the environment (thermal conditions, ocean depth, geography).

Perhaps because the information load is potentially so great, simple "decision rules" are often adopted (at least verbally): e.g., for time-of-fire, avoid counterdetection; or fire as soon as within maximum weapon range and in possession of a range solution. Unfortunately, these rules imply natural cutoff points that may not exist: the probability of counterdetection can increase gradually during an approach, as can the quality of a solution. More importantly, they exclude, at least verbally, a balancing of tradeoffs - such as accepting a small risk of detection in order to accomplish a mission objective.

4.2 The Decision Makers

How do Commanding Officers utilize information in planning an attack? Are there important differences in their data-gathering and decision-making styles?

Evidence which we have gathered suggests that such differences are quite pronounced. Responses of four former attack submarine officers to a hypothetical approach and attack scenario are summarized in Appendix C. Dramatic differences were found in:

- level of aggregation - e.g., whether the major objective was "killing the target" or moving him into weapon range, preserving own ship or avoiding counterdetection;

- number of evaluative dimensions - e.g., whether killing the target and preserving own ship were considered simultaneously in specific decisions;

- use of cutoffs - e.g., whether actions were triggered by thresholds based on weapon range or counterdetection range;

- attitude toward risk - e.g., whether one or both of two targets was engaged;

- amount of information - i.e., number of items which were consulted from those currently available on board submarines which were requested; and

- pattern of information search - i.e., the amount of evidence (number of different sources) sought for each item, and whether search among items was organized by source or by item.

4.3 Testbed Characteristics

Approach and attack planning is only part of the information management problem in the combat center of a submarine. Several characteristics, however, made it appealing as a context for prototype aid development:

- its high stakes and high expected frequency of occurrence in wartime,

- the complexity of the decisions involving uncertainty and competing objectives,

- the fact that the time available for decision making is limited, but sufficient for utilization of an aid, and

- the evident appropriateness of an information support system which caters to the personal styles of its users.

5.0 A PERSONALIZED AND PRESCRIPTIVE ATTACK PLANNING AID

The feasibility of implementing the general concept of a personalized and prescriptive aid has been subjected to test in the context of submarine approach and attack. The resulting prototype aid is designed to facilitate both personalized, flexible manipulation of a data base and timely, valid decisions. Advanced features of interface design minimize the labor that must be devoted to making the system work and free the user's attention for the problem at hand.

Portions of the prototype aid design are at varying stages of implementation. Elements of the data base, Planning Module, and Selection Module have been programmed, and will be described here in the context of the more complete conceptual design.

5.1 Implementation

The purpose of the current physical implementation of the attack planning aid is to illustrate, at low cost, the essential features of the user-system interface and to provide a prototype suitable for demonstration and testing. It is by no means intended to represent the final form the aid would take in a military setting.

The most important feature of the aid interface is its simplicity for the user. From his point of view, the current system consists of a high-resolution color display, a joystick, and function key. (A more detailed description of the system is in Appendix A.) As in the Spatial Data Management System (Herot et al., 1978; Bolt, 1979), the user can traverse the space of available display options, selecting items for detailed examination and generating his own inputs, with surprisingly little effort. The joystick-plus-key control - unlike most keyboards - frees the user's visual attention for whatever appears on the display.

An equally critical feature of the finished system will be its fit within the submarine combat center. The aid is designed primarily for the Commander or a high level aide (e.g., the Approach Officer), and should be fully consistent with the command role. For example, although a large-screen command-dedicated display has been tentatively proposed for new generation submarine combat centers (e.g., NUSC, 1978), a problem with this idea, as usually conceived, is that it would discourage the Commander from moving about the combat center (cf., Cohen et al., 1982). The present system design, with a light-weight hand-held joystick-plus-key, would give the Commander constant visual access and control, with no sacrifice of freedom and flexibility.

5.2 Data Base

The data base contains information at all levels of aggregation: from ultimate combat objectives (i.e., killing the target, surviving), to intermediate goals (i.e., critical combat events which influence the achievement of ultimate objectives, like counterdetection and first shot kill), to basic inputs. Basic inputs include (in principle) most of the data currently available for display on board submarines: e.g., information about target range, ocean thermal conditions, threat weapons and sensors, etc.

Inferences and forecasts regarding combat critical events are derived by applying a set of prescriptive models to basic inputs. If the Commander proposes a tactical alternative for evaluation (i.e., a target, weapon, and set of approach maneuvers) forecasts of critical events may be computed conditional on that tactic.

Evaluation in terms of ultimate objectives is accomplished by further prescriptive aggregation. At this level, probabilities

for the outcomes of ultimate concern (killing the target and surviving) are computed and combined with assessed values of target and own ship; an overall figure of merit (expected utility) is then derived for the tactic under consideration.

The currently implemented data base is by no means complete. Basic inputs have not been programmed for display - because this information is already available on submarines. Our focus, for demonstration purposes, has been on higher level aggregations and the prescriptive modeling required to derive them (as described in Appendix B). Nonetheless, basic inputs have been fabricated for a single hypothetical target and weapon. Algorithms have been programmed for the derivation and display of the following probabilistic forecasts of critical events, for the hypothetical target and weapon:

- first shot kill
- counterdetection
- successful target counterattack

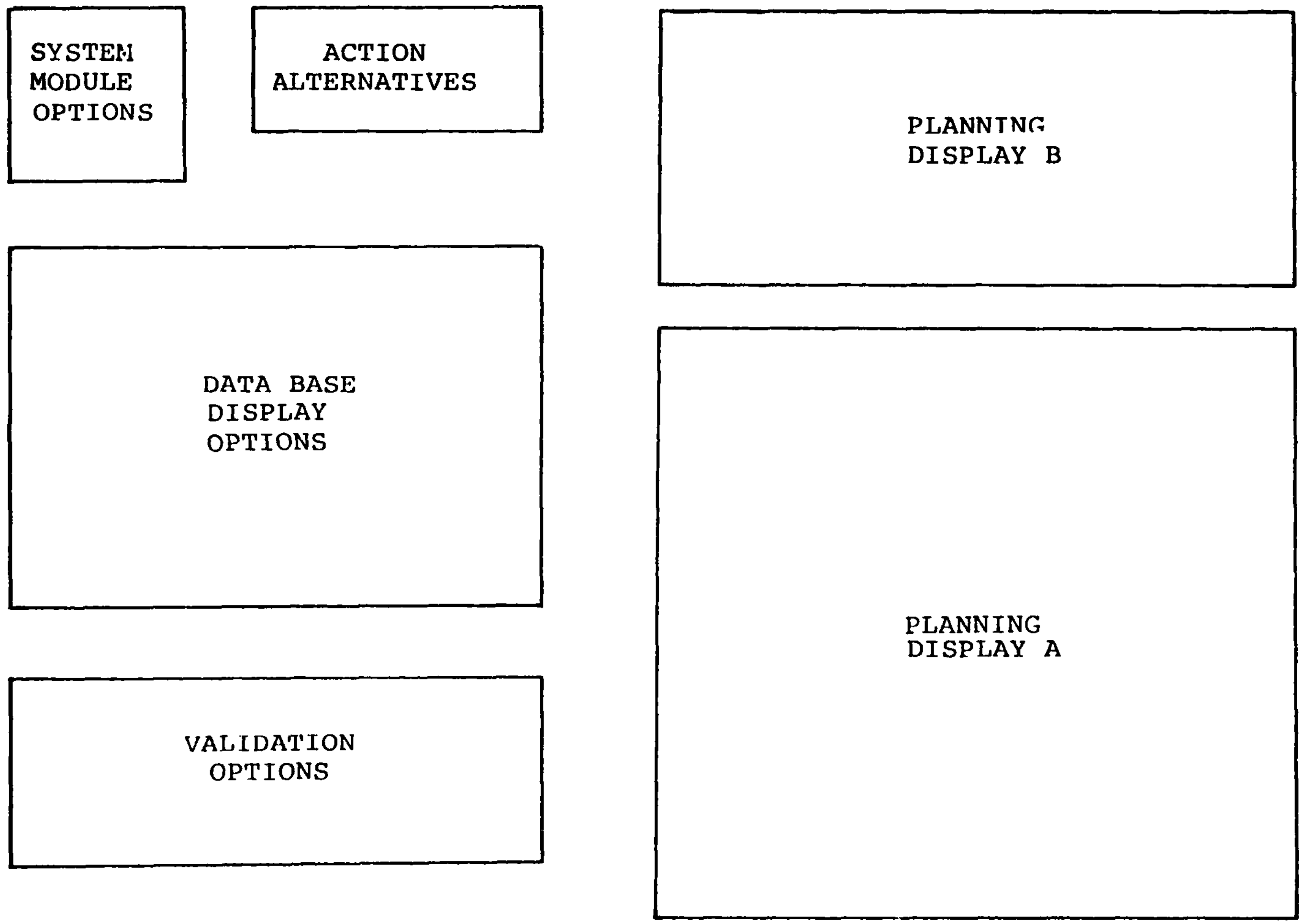
Prescriptive algorithms have been programmed to derive the following displays of ultimate objectives:

- probability of kill
- probability of survival
- figure of merit

5.3 Planning Module

The Planning Module divides a display screen into specialized areas, as shown in Figure 5-1. The box labeled "Data Base Display Options" orients the user in two important ways:

Figure 5-1. Outline of Planning Module Display



- It outlines the portion of the data base which is immediately available for display; and
- it tells the user what his current display selection is.

If the current display involves an inference or a forecast, the "Validation Options" box outlines in detail the portion of the data base which provides the evidence from which it is derived.

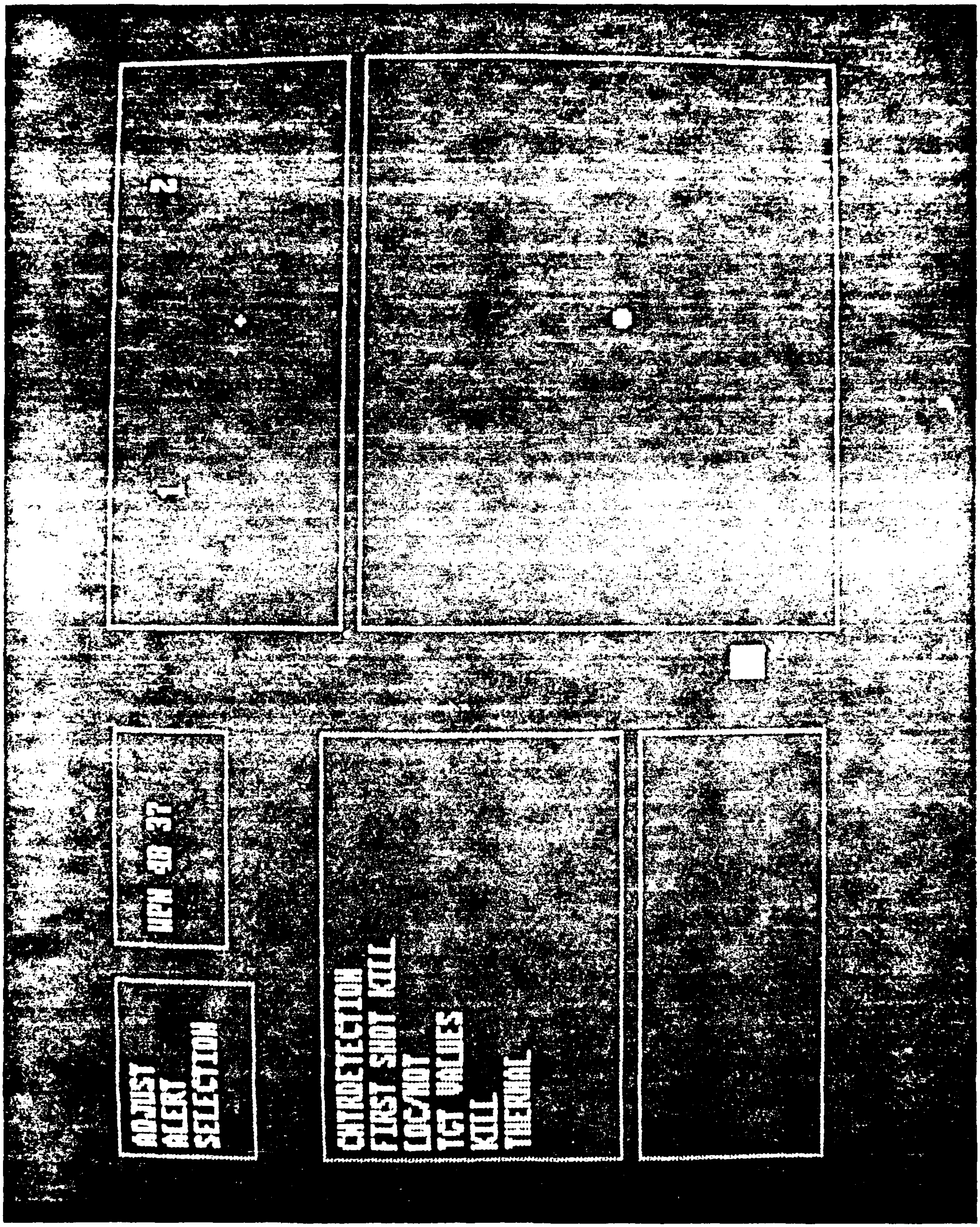
Information selected for display appears in the "Planning Display B" (PD-B) box. Planning Display A (PD-A) provides a complementary overview: e.g., in attack planning it shows the locations of contacts and own ship.

Action alternatives can either be selected from a given list or generated by the user for evaluation. In the latter case, they are listed explicitly in the "Action Alternatives" box; or if there is a natural pictorial representation, they may be depicted in either or both of the Planning Displays. Thus, target alternatives appear in PD-A and approach paths are drawn by the user in PD-B.

From the Planning Module the user has direct, easy access to a number of more specialized routines, as indicated in the "System Module Options" box. These routines enable the user to customize the operation of the Planning Module for his own purposes: he can make selections fc the Data Base Display Options box, adjust default values in the data base, set cutoffs or alerts, and establish thresholds for prescriptive prompts.

5.3.1 <u>The planning module in use</u>. In Figure 5-2 we have the entire Planning Module display as the Commander sees it before making inputs. Planning Display A gives the big picture: in this hypothetical scenario, it shows two targets ("1" and "2")

Figure 5-2. Planning Module Display Prior to User Inputs



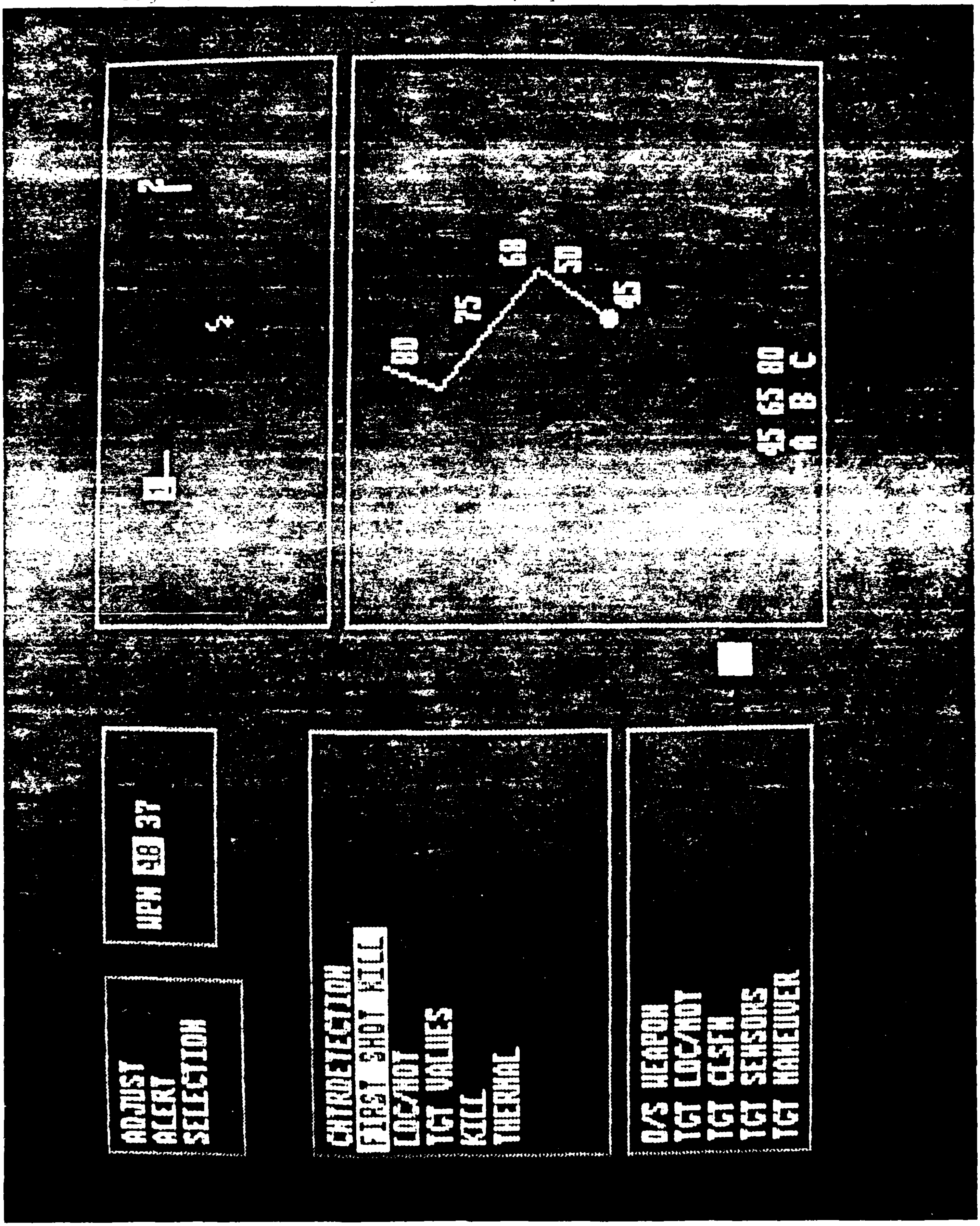
and the location of own ship as a green cross. (Subsequent versions will offer the option of uncertainty ellipses representing target location, and fans indicating uncertainty about target course and speed. The user will also be able to vary the scale of PD-A and PD-B. In the current implementation, all distances are arbitrary for security reasons. Thus, scale markings have been omitted.)

The Commander may select information for display from any level of aggregation in the data base. For example, he might call up a forecast of the probability of own ship's killing the target, contingent on some tactic; or he might prefer to examine some of the lower level probabilities which influence the overall probability of kill, e.g., the probability of counterdetection, or the probability of a first shot kill. Finally, the Commander might use the aid to analyze the location and motion (LOC/MOT) of the target.

In Figure 5-3 the Commander has used the joystick-plus-key to indicate (1) the tactical option (consisting of approach maneuvers, weapon selection, and target priority) that he wishes to evaluate, and (2) that his current concern is the probability of a first shot kill.

These inputs need take no longer than a few seconds. The joystick controls the motion of a cursor on the screen in a natural spatial manner. As the cursor moves along the list of data base display options or validation options, the indicated item blinks. Pressing the button means that the blinking item is selected, and the selected item is then highlighted. (Selections can be canceled by pressing the button a second time or by entering another selection.) Weapon options (e.g., "48" or "37") are chosen in precisely the same way. Target selections are made from the spatial display in PD-A, by moving the cursor

Figure 5-3. Planning Module Display After User Interaction



to the location of the desired target and, again, pressing the button. (For quickness, the cursor skips over intervening spaces among discrete items.) The Commander in Figure 5-3 is considering the alternative of firing at target 1 with a Mark 48 torpedo.

The Commander also uses the joystick-plus-key to draw an approach path in PD-B. The region around own ship is here shown on a larger scale than in PD-A. Legs are created one by one by moving the cursor to the desired point and pressing the button; that point is then connected by a line to the previously indicated point (or, on the first leg, to the own ship symbol). (Later portions of any path can be erased by moving the cursor to an already used point and pressing the button; if the cursor is placed on the own ship symbol, the entire path will be erased.) Individual users can vary in the preferred time span over which planning takes place, by varying the lengths of the approach maneuvers submitted for evaluation.

As the user draws the approach path in PD-B, PD-A replicates it on a smaller scale and shows, simultaneously, how the locations of the two targets are expected to change. (This computation at present assumes a constant own ship speed).

After the Commander indicates a tactical alternative and a data base option, he moves the cursor back to "home" (the yellow square in the central margin) and presses the button. PD-B then displays the requested information: i.e., the predicted probabilities, at different points on the approach path, of a first shot kill if own ship fires at that point. In the current purely hypothetical example, the probability of first shot kill is assessed at the present as .45, but rises to .80 at the last point on the indicated path. In the meantime, the validation box indicates that these probabilities were derived from informa-

tion about the user-selected own ship weapon, analysis of the target's location and motion, target classification, target sensors, and target maneuvering capabilities.

5.3.2 Stored alternatives. Letters A, B, and C in PD-B refer to a set of previously examined tactical alternatives (i.e., different selections of target, weapon, or approach path) which the Commander has stored. The numbers above each letter summarize the currently relevant information for each alternative: i.e., the maximum probability, across times of fire, of first shot kill for each alternative. Since the currently displayed alternative is C, the Commander may conclude that - in terms of probability of kill at least - options A and B appear to be significantly inferior.

When the cursor is moved out of the PD-B box, any unerased (and not previously stored) path is stored and a letter denoting that path appears at the bottom of the box. Paths can be recovered by moving the cursor to the appropriate letter, which then blinks, and pressing the button; the selected letter is then highlighted. (A path can be erased from storage by pressing a second time - but a change of mind is possible since the erased path will remain drawn on the screen.)

5.3.3 Personalized information search. The Commander may now feel he has as much information as he needs. Alternatively, he can pursue the Planning Module dialogue in any of several directions:

- He can evaluate the credibility of the current display by calling up options from the validation box;
- He can examine additional tactical alternatives by indicating a new choice of target, weapon, or approach path;
- He can evaluate the current tactical alternative or previously examined ones in the light of other combat concerns.

An important feature of the aid helps the user to explore the data base in the way that most suits his decision-making style. He can efficiently organize his search either by alternatives or by evaluative "dimensions" (i.e., forecasts of critical events or ultimate goals). In the former case, after generating or retrieving a tactical alternative, and without selecting anything from the Data Display box, the user moves the cursor to home and presses the function key. The aid automatically displays in PD-B the item listed first in the Display Options box; a subsequent button depression gives the next item in the column, and so on. The user can thus quickly size up a given alternative on all pertinent dimensions of evaluation.

Similarily, he can quickly scan a set of options with respect to one dimension. To do so, he selects the dimensions from the Display Options box without selecting a tactical alternative. Button pushes at home then cause the display to step through the sequence of stored actions (A, B, C, etc.).

The user-interfaces for the Planning Module and the Selection Module have been completely programmed; their functioning is circumscribed only by the gaps noted above in the data base implementation.

5.4 Selection Module

The Selection Module allows the user to personally select the portion of a large data base which will be immediately accessible through the Planning Module. The data base items likely to be needed by a particular decision maker will depend on the operational situation he anticipates. The Selection Module expedites his access to that information; but at the same time, because of its streamlined interface, it permits him to alter his prioritization and retrieve any other information quickly and easily.

The Selection Module is entered directly from the Planning Module. The initial display, shown in Figure 5-4, outlines the entire "display-option space" of the data base. That space is organized hierarchically, according to the three levels mentioned in Section 5.1: tactical evaluation with respect to overall objectives; forecasts and inferences of combat critical events (which may pertain to either the approach or attack phase); and basic inputs regarding current status (broken down into information regarding contacts, own ship, and environment). (The currently implemented display shown in the figure is a quite incomplete version of the final attack planning data base.)

To make selections from this display, the user again moves the cursor in a natural spatial manner to the pertinent item. A press of the button causes that item to vanish from its standard spot and reappear in the Choice list on the right. In Figure 5-5, a number of items have been selected in the order shown. The user can insert items anywhere in the list: If he moves the cursor to an item in the Choice list and presses the button, a blank appears above that item; if he now selects a new item from the data base listings, the new item appears in the blank. (A Choice list item can be deleted - i.e., moved back to the original list - by selecting it with the cursor and pressing twice.)

When the user selects "Exit", the Planning Module returns. The ordering of data base items in the Display Option box will now correspond to the order he has selected.

5.5 Adjust Module (Conceptual Design)

The Adjust Module has two important functions: incorporation of subjective inputs into the Data Base and what-if planning.

Figure 5-4. Selection Module Display Prior to User Inputs

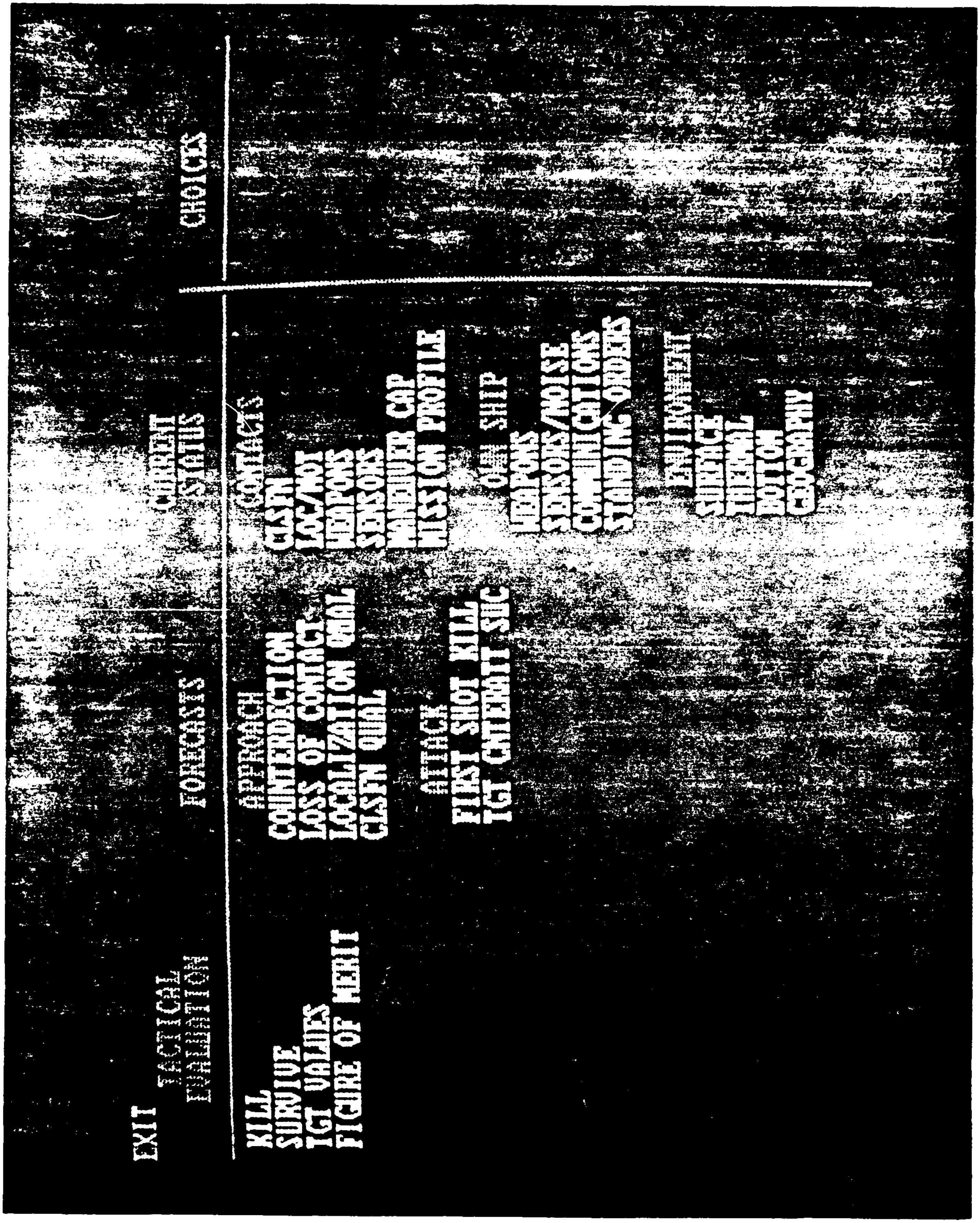
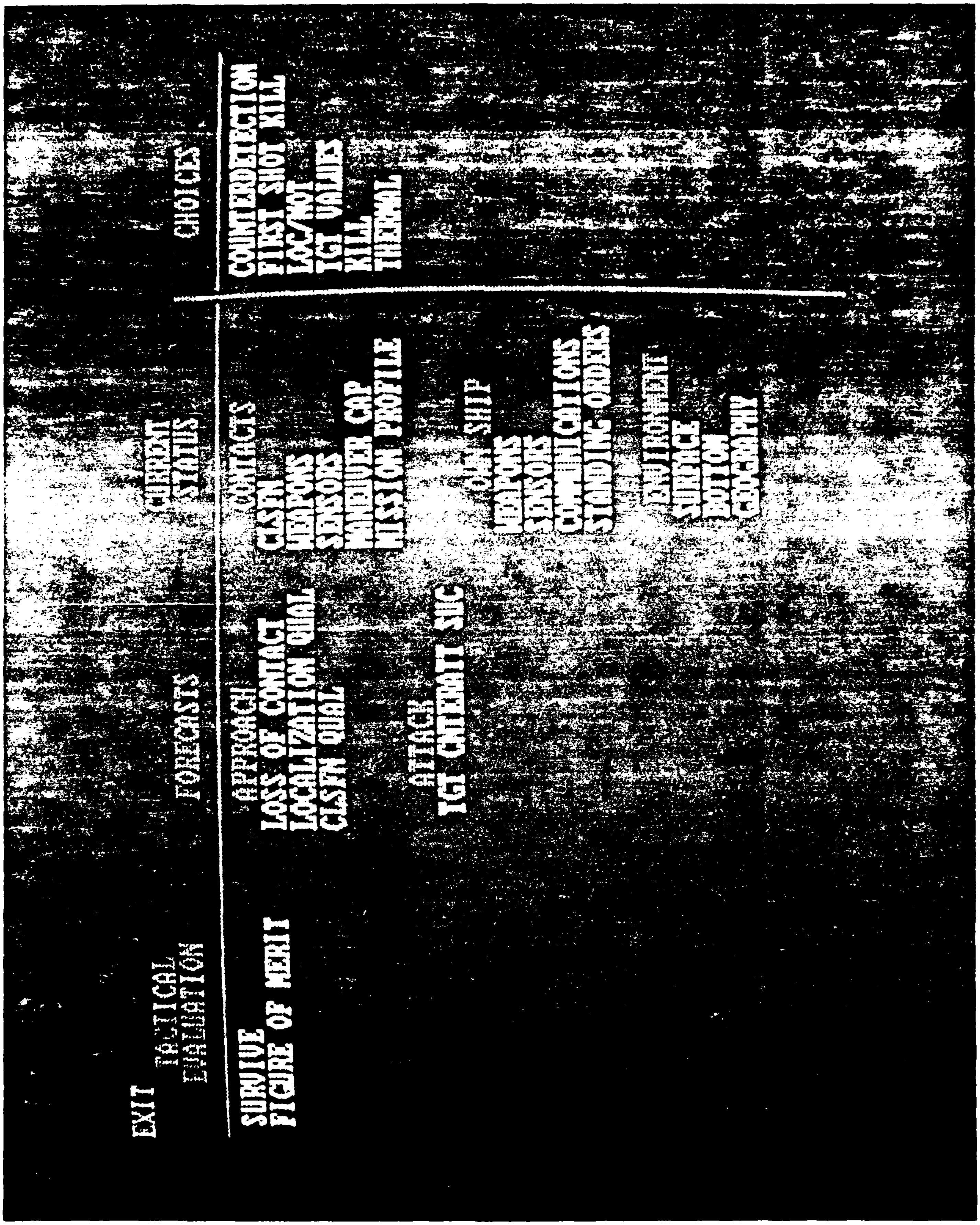


Figure 5-5. Selection Module Display After User Interaction

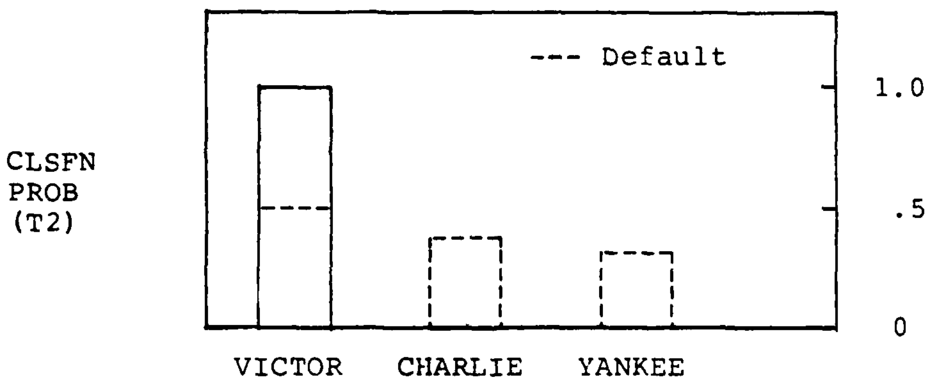


Basic inputs in the data base are derived from a number of sources: e.g., sensors, third party communications, intelligence, and own ship equipment specifications. None of this information is infallible: much of it already involves a degree of judgment; and some of it might well be improved by the judgment of appropriately experienced people on the spot (see Cohen, 1982, for the role of subjective judgment in improving estimates of target range). The Adjust Module enables the user to insert his own judgments at any level of aggregation (e.g., from range accuracy to probability of a kill) and then observe the implications of the adjustment for any higher level. In the same way, the adjustment option allows the user to explore hypothetical states of affairs. In both uses of the Adjust Module, the original default values are retained and may be restored at any time.

The user selects a data base item for adjustment from a display much like the Selection display of Figure 5-4. A graphical representation of the requested information then appears, and the user employs the cursor-plus-key to draw in new values. For example, Figure 5-6 shows a conceptual display of classification probabilities for Target 1. Default probabilities (indicated by dotted lines) are computed automatically on the basis of sensor cues, third party reports, and/or intelligence information. The user inserts new values (the solid lines) by moving the cursor to the desired position on the vertical scale above the relevant classification type, and pressing the button. (The final probability is computed automatically so that the total sums to 1.0. The user deletes a value by entering a new one; and he may restore default values by selecting "Default.")

In this example, the user has chosen to explore the assumption that target 1 is a Victor. If he now returns to the Planning Module, all subsequent displays (e.g., forecasts of counterde-

Figure 5-6. User Adjustment of Classification Probabilities



tection probability or first-shot kill probability) will be conditional on that assumption, and appropriately labeled as such.

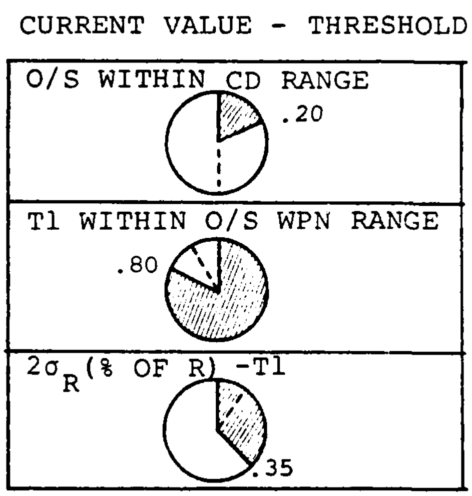
5.6 Alert Module (Conceptual Design)

In decision making, the task of compairing a sizeable number of options with respect to multiple dimensions can be simplified by utilizing cutoff criteria. For example, options which fail to achieve a critical level on some dimension or combination of dimensions may be quickly eliminated. Although there is danger that important compensating advantages will be overlooked, this strategy is often likely to be cost/effective. The Adjust Module has two functions: It customizes the Planning Module for the strategy of evaluating options by reference to cutoffs; and at the same time, it provides an alerting system in real time when those cutoffs are crossed.

In the Adjust Module cutoffs can be quickly and easily set on any variable in the Data Base, at any level of aggregation. After the user selects a set of variables from a display like that in Figure 5-4, values of each requested variable are displayed graphically, as shown in Figure 5-7. In this example, the current probability estimate for being within counterdetection range (of either T1 or T2) is .20; for having target 1 within own ship weapon range, .80; and the 95% interval of uncertainty (2) concerning T1's range, as a percentage of T1's estimated range, is ±35%. The user sets cutoff thresholds (shown by the dotted lines) by moving the cursor to the appropriate position in the diagram (anywhere along the desired radius) and pressing the button.

When the user returns to the Planning Module, he finds a new Data Base Display option called "Alerts." If he selects this option, his cutoffs are incorporated into a PD-B display which

Figure 5-7. Alert Module Display of Current Values and User-Set Thresholds



forecasts - for the tactical alternative under consideration - when and if each threshold will be crossed. Thus, Figure 5-8 shows where on the approach path the objectives (or counterobjectives) with respect to weapon range and counterdetection are first expected to be crossed, and indicates that the desired range accuracy may not be achieved at all under this set of maneuvers. Utilizing the organized search procedure made available by the Planning Module, the user can scan quickly through a series of stored action alternatives, comparing each one to a multidimensional conjunctive or disjunctive criterion.

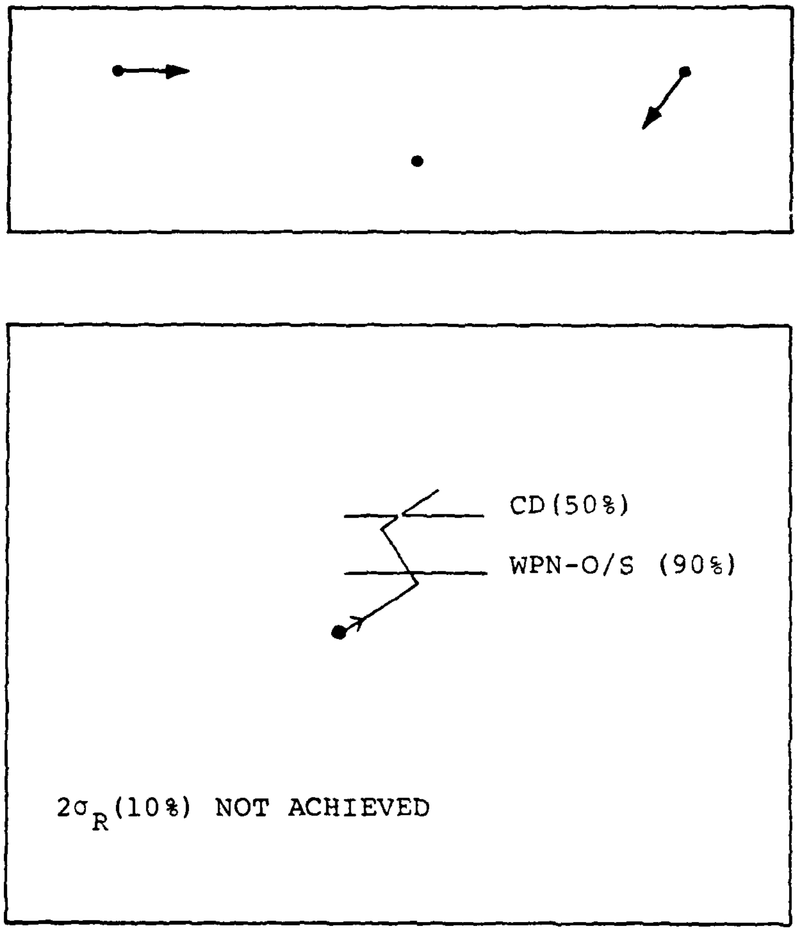
When a previously set cutoff is <u>actually</u> crossed, the Planning Module alerts the user by placing the word "ALERT" next to the appropriate item in the Data Options Box (the item is added if not already present) and/or, at the user's option, by producing an auditory signal.

5.7 Advisory Module (Conceptual Design)

Advisory prompts in the Planning Module provide a sort of "peripheral vision" for the user, warning him when there is something of interest outside his current focal area. Thus, a considerable degree of flexibility in the user's allocation of time and attention to information can be combined with reasonably unobtrusive prescriptive checks and safeguards.

The objective is not simply to alert the user whenever there is some difference, however small, between his judgment and the output of a prescriptive model. The difference must be large enough to <u>matter</u>, in the actions to be selected and in their expected outcomes (cf., Cohen and Freeling, 1981). Before prompting, therefore, the prescriptive model compares the expected utility of the "best" action with the expected utility of the action suggested by information the user has observed.

Figure 5-8. Planning Module Forecasts
for User-Set Thresholds

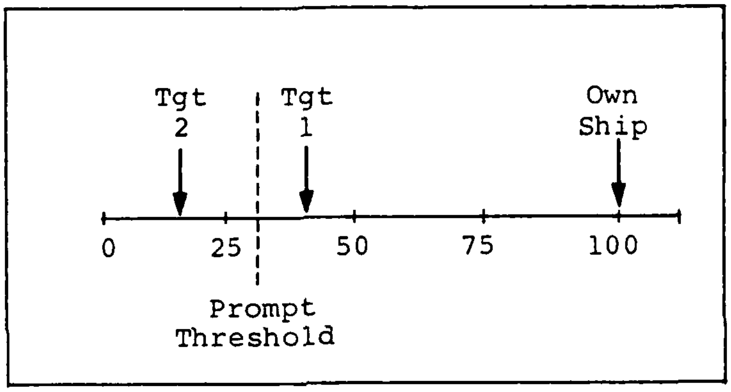


The Advisory Module enables the user himself to determine how large that difference must be to warrant a prompt.

The Advisory Module display in Figure 5-9 enables the user to set such a threshold on an easily interpreted utility scale. The value of own ship survival is set arbitrarily at 100; the values of killing various targets may be provided by default (based on mission directives) or adjusted by the Commander (see Appendix B for a description of the scaling procedure). The user moves the cursor to the desired threshold point on this scale and presses the button. The effect, in this example, is that unless the prescriptive model estimates a potential prompt impact of at least 28% of the value of own ship survival, no prompt will be provided. (In practice, the user need not be concerned with the interpretation of the scale; after some experience he can simply set the threshold to achieve the desired frequency of prompts.)

The Planning Module monitors the user's selection of information and derives a rough hypothesis as to the action implied by that information. (It may do this by aggregating the set of rank orderings of tactical alternatives which are produced by the individual dimensions which the user has observed.) It then compares the presumed "user-preferred action" according to the aggregated rank ordering with the best action according to the prescriptive model. If the difference in expected utility exceeds the user-set threshold, the next step is to determine which items as yet unobserved by the user would be most helpful. The Planning Module prioritizes unobserved dimensions in terms of how well they differentiate between the "user-preferred" option and the best option according to the prescriptive model. These are the dimensions most likely to fulfill the role of "devil's advocate" - i.e., they are most likely to lead the user to constructively question his current assumptions. Asterisks

Figure 5-9. Advisory Module Display of User-Set Tolerance for Disconfirming Information



are displayed next to these critical dimensions in the Data Base Options box (if not already present, the dimension is added to the list) - signifying to the user that information is available which appears to clash with information he has already observed.

5.8 Summary

The attack planning aid gives concrete form to the notion of a personalized and prescriptive aid. Direct use of the Planning Module enables the user to sample information from any preferred level of aggregation in the data base, organize his search for information efficiently in terms of either alternatives or attributes, and vary the number of options examined, the amount of information requested concerning each, and the time into the future which planning encompasses. Moreover, this module clearly distinguishes conclusions from evidence, and displays the sources from which each inference is derived.

Personalizing and prescriptive features are enhanced by customizing modules. The Selection Module allows the user to prioritize information for immediate access and efficient search. The Adjust Module accommodates individual differences in beliefs and preferences and - from a prescriptive point of view - adds a potentially valuable source of information (the user) to the data base. The Alert Module facilitates individual heuristic strategies which evaluate actions by reference to cutoffs (as opposed to tradeoffs); it also alerts a user, whose attention may be otherwise engaged, when cutoffs are crossed. Finally, the Advisory Module allows the user to determine the degree of prescriptive prompting that occurs when potentially disconfirming data exist which he has not yet observed.

6.0 INFORMAL DEMONSTRATION OF THE PROTOTYPE AID

A design and its users must evolve together. When an aid defines new tasks and offers capabilities not previously experienced, assessments based exclusively on current user practice are of limited value; the user must be able to respond to a concrete prototype of the proposed system. Such responses, over many iterations, may lead both to user acceptance of new prescriptive possibilities and to significant alterations in the details and the objectives of the initial design (cf., Keen, undated).

As a first step in this process of "middle-out" design, two former submarine officers were exposed to an initial version of the attack planning aid. After a short briefing, they operated the aid within the hypothetical scenario described in Section 5.0. Since data base information was available regarding only one hypothetical target and weapon, the focus of the exercise was the selection of approach maneuvers and time of fire.

Both users responded favorably to the aid. More significantly, they managed to use the aid in dramatically different ways in the same decision context (although some of the information they requested was not yet implemented in the prototype).

In one case, the aid supported an initial decision of whether to "sprint" (i.e., move quickly toward the target) or "drift" (i.e., maneuver more slowly to gather information on range and classification). This user requested projections of target localization accuracy conditional on these two kinds of approach. In the second case, the decision maker preferred to use the aid within a more restricted planning horizon, yet sampled information at a higher level of aggregation. The "approach maneuvers" he evaluated consisted of a single leg, and

his major concern was the probability of counterdetection. (This user would have preferred a display of counterdetection cutoffs, as in the not-yet-implemented Alert Module.)

Both users expressed a need to validate the displayed forecasts (of localization accuracy and counterdetection probability, respectively) by examination of evidence. In addition, both users requested some sort of optimization procedure whereby the aid, rather than the user, generates alternatives.

This demonstration is by no means meant to serve as a rigorous test of the aid: the "subjects" were too few, the prototype aid and the hypothetical scenario too incomplete. (Moreover, inputs from these officers had been utilized earlier in the design process, as described in Appendix C; we think it unlikely, but this role might have biased the outcome of the subsequent demonstration.)

Nevertheless, the results at least suggest that a personalized and prescriptive attack planning aid can be useful to attack submarine decision makers, and that it can flexibly accommodate individual differences in their decision-making styles.

7.0 CONCLUSIONS

A general concept and a specific prototype system have been developed to accommodate features of individual decision-making performance against a background of prescriptive signposts. The feasibility of such an approach can ultimately be assessed only by reference to user acceptance and improved quality or speed of decisions. Nonetheless, the initial indications are favorable. The existence of individual differences in information use and decision making has been confirmed in the special context of attack submarine approach and attack (Section 4.0, Appendix C). A planning aid which is both personalized and prescriptive, and which employs an advanced user interface, has been designed and, in critical features, implemented (Section 5.0). Finally, a preliminary demonstration suggests that the system is able to cater effectively and acceptably to its users (Section 6.0).

The present design is, of course, not yet fully implemented; moreover, it is subject to numerous improvements - in the interface, the prescriptive models, and in the character of its basic functions. (Some of these are described in Appendix D.)

Perhaps the most exciting avenue for further development, however, is the exploration of new applications for the basic principle of blending personalized and prescriptive support. We have illustrated the principle in a specific decision context which is, however, representative of many others: the submarine approach and attack problem shares features with numerous command and control settings where the risk of counterdetection is balanced against the goal of harming a foe. We believe that still other kinds of decisions (e.g., resource allocation, intelligence analysis, or system evaluation) are amenable to the same basic set of principles - though the decision aiding functions, as embodied in the system modules, may need to be extended or generalized in as yet undetermined ways.

For example, a "Structuring Module" might help the user define his own prescriptive links between basic inputs and the variables to be inferred or forecasted. In these new contexts, prescriptive prompts might take on new functions as well - for example, alerting a user that two information sources, both of which he regards as credible, have contradicted one another; hence, the credibility of one or both should be revised downward in this and in future inferences.

The submarine setting itself affords ample opportunities for testing out new applications. The attack planning aid (suitably completed in its own right) might become the nucleus of a more general submarine information management system, with applications to a quite different set of missions - e.g., surveillance or close support of a task force. New dimensions of difference among decision makers are likely to turn up in these situations, and novel methods of accommodating them (and perhaps tempering their non-prescriptive effects) willl have to be devised.

In these, as in all cases where new systems are proposed or introduced, the last word is with the user.

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APPENDIX A

SYSTEM CONFIGURATION

To permit preliminary interactive testing and demonstration of an illustrative system, while keeping costs down, we selected the IBM Personal Computer (IBM-PC) as the core of our hardware system. This new system, based on a high-speed 16-bit microprocessor, offers somewhat more capability than its competitors, particularly with regard to graphics and, in particular, interactive color graphics. The system actually employed included the following components and features:

- 128 K-bytes of RAM memory (256K available);
- a color-graphics interface and Amdek Color-II high-resolution RGB monitor;
- an analog-digital interface and joystick with simple function key;
- an 80-cps matrix printer; and
- dual diskette drives with 160KB capacity each.

APPENDIX B

PRESCRIPTIVE MODEL FOR ATTACK PLANNING

The attack planning aid data base contains prescriptive models of two rather different types:

(1) a generic "macromodel,"

(2) a set of special-purpose, detailed "micromodels" that provide inputs for the macromodel.

The macromodel operates at higher levels of the data base, aggregating probabilities of critical events into probabilities of ultimate objectives and figures of merit for attack plans. Micromodels link basic inputs to forecasts of critical events, and the latter to one another.

In this appendix we will briefly sketch the features of the macromodel which has been implemented in the demonstration aid. This model has several somewhat different functions. First, it provides "figures of merit" for different tactical alternatives - which the Commander may explicitly consult (through the Planning Module) in making his decision. Second, it provides a rational framework for Data Base organization, determining what information is relevant and in what way. The Commander is free to sample this information at any level he chooses. Finally, the prescriptive macromodel triggers prescriptive prompts when the user's choice of information for display appears, according to the model, misleading.

B.1 Macromodel: Decision Tree

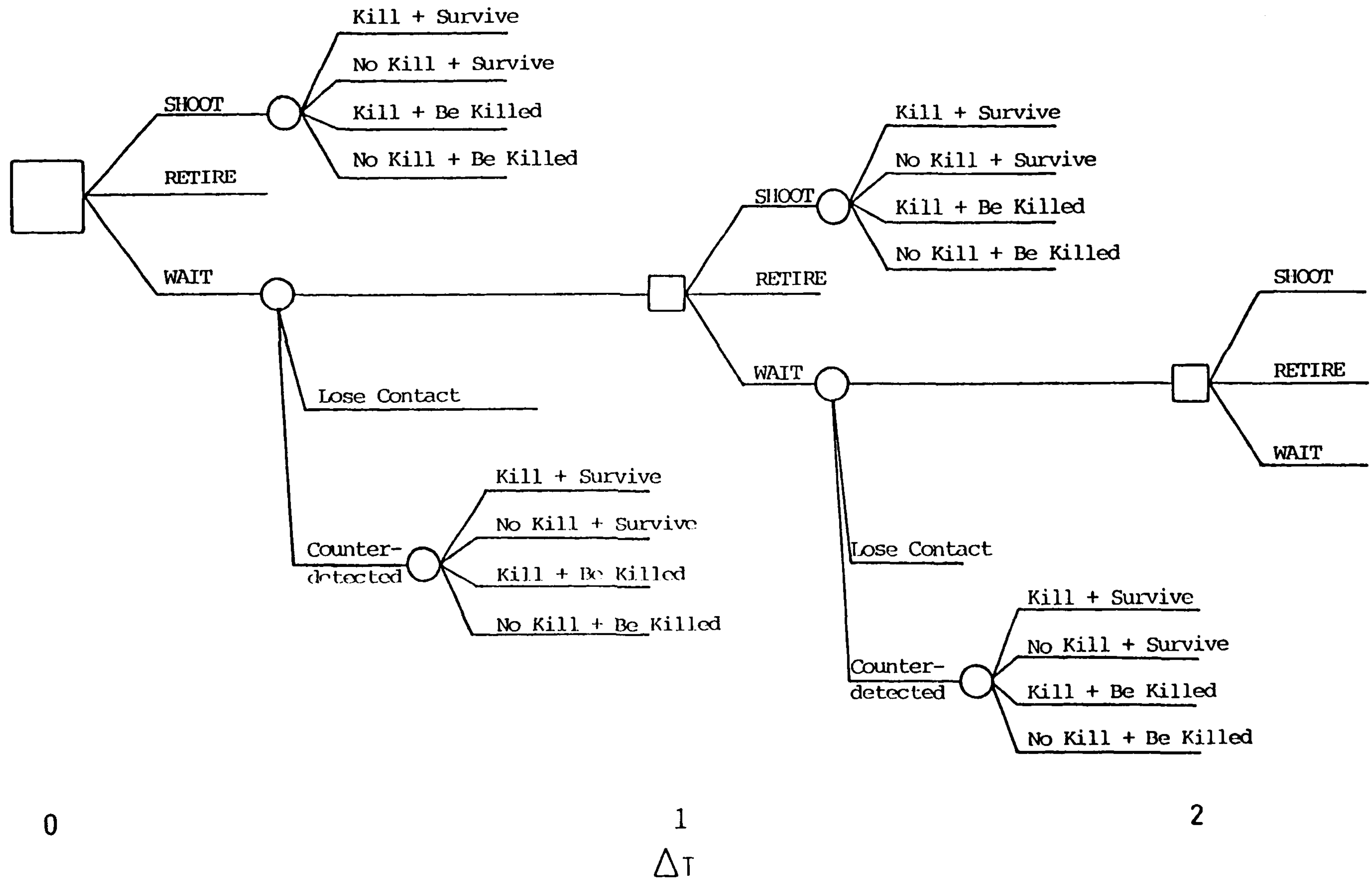
The time of fire decision problem is represented by a decision

tree. Figure B-1 consists of a series of square "decision nodes" and round "chance nodes" arranged in the order in which decisions and chance events might occur. (For the sake of convenience, a continuous process has been divided into discrete intervals.) Thus, at time $\Delta t=0$ (on the far left) the CO must decide between shooting, retiring, or continuing the approach. If the CO decides to shoot, there is uncertainty about which of four events will eventually happen, defined by the possible combinations of killing the target and not killing, and surviving and not surviving. If the CO decides to wait, he may successfully continue to approach, but he runs the risk of losing contact or being counterdetected. (Losing contact is equivalent to maintenance of the status quo, i.e., failing to kill and surviving.) If own ship is counterdetected, possible outcomes again include the combinations of killing and being killed. But if own ship successfully continues to approach, the CO faces at the end of the interval his original choice between shooting, retiring, or waiting.

The decision tree requires two kinds of inputs: probabilities and utilities. Probabilities are estimated for each uncertain event - i.e., for each branch emerging from a chance node. Utilities (or degrees of preference) are assessed for each outcome - i.e., for each total path through the tree, consisting of a particular sequence of choices and chance events. We have assumed that the utility of a path is determined entirely by which of the four possible events (killing x surviving) occurs at i.s end.

The entire tree in Figure B-1 as well as its inputs are conditional on the *prior* decisions of selecting a target, a weapon, and a set of approach maneuvers: An expanded tree might have been drawn representing those decisions as well. The points made here, however, could be essentially unchanged by that added complexity.

Figure B-1. Decision Tree for Time-of-Fire Decision



B.2 Macromodel Analysis

The purpose of the prescriptive model is to help the CO, at $\Delta t=0$, assess the strategies that lie open to him - and perhaps tentatively to select one. A strategy is a complete plan of action for the time of fire decision problem - it specifies a choice for every decision node he might encounter before reaching the end of a path. For example, one possible strategy is "wait at $\Delta t=0$ and shoot at $\Delta t=1$."

Each strategy can lead to a number of possible outcomes. For example, in the strategy "wait at $\Delta t=0$ and shoot at $\Delta t=1$," there is a chance of losing contact or being counterdetected during the interval starting at $\Delta t=0$; if one does manage to shoot at $\Delta t=1$, there are then the chances of being killed without killing, killing and being killed, etc. Each of these outcomes or paths has a probability, which is a function of the sequence of chance events required to produce it.

An "expected utility" is assigned by the aid as a "figure of merit" to each strategy. This quantity is the sum of the utilities for each possible outcome of the strategy, weighted by its probability of occurrence.

The recommended strategy (if one accepts the model) is the one with the highest expected utility. In fact, of course, the CO would not have to commit himself to a complete strategy at $\Delta t=0$. Even if he performs the immediate action (e.g., waiting) suggested by the recommended strategy, options for the future are not foreclosed. (Indeed, additional information obtained during the approach, for example, about target capabilities or value, may cause the optimal time of fire to shift.)

B.2.1 Aggregating probabilities. The following notation will be used to represent the probabilities which are aggregated by

the macromodel; they are illustrated in Figure B-2:

$A_{x,t}$ = probability of outcome x given own ship attacks target at time t

$W_{y,t}$ = probability of outcome y given own ship decides to wait at time t

$C_{x,t}$ = probability of outcome x given own ship is counterdetected during approach following time t

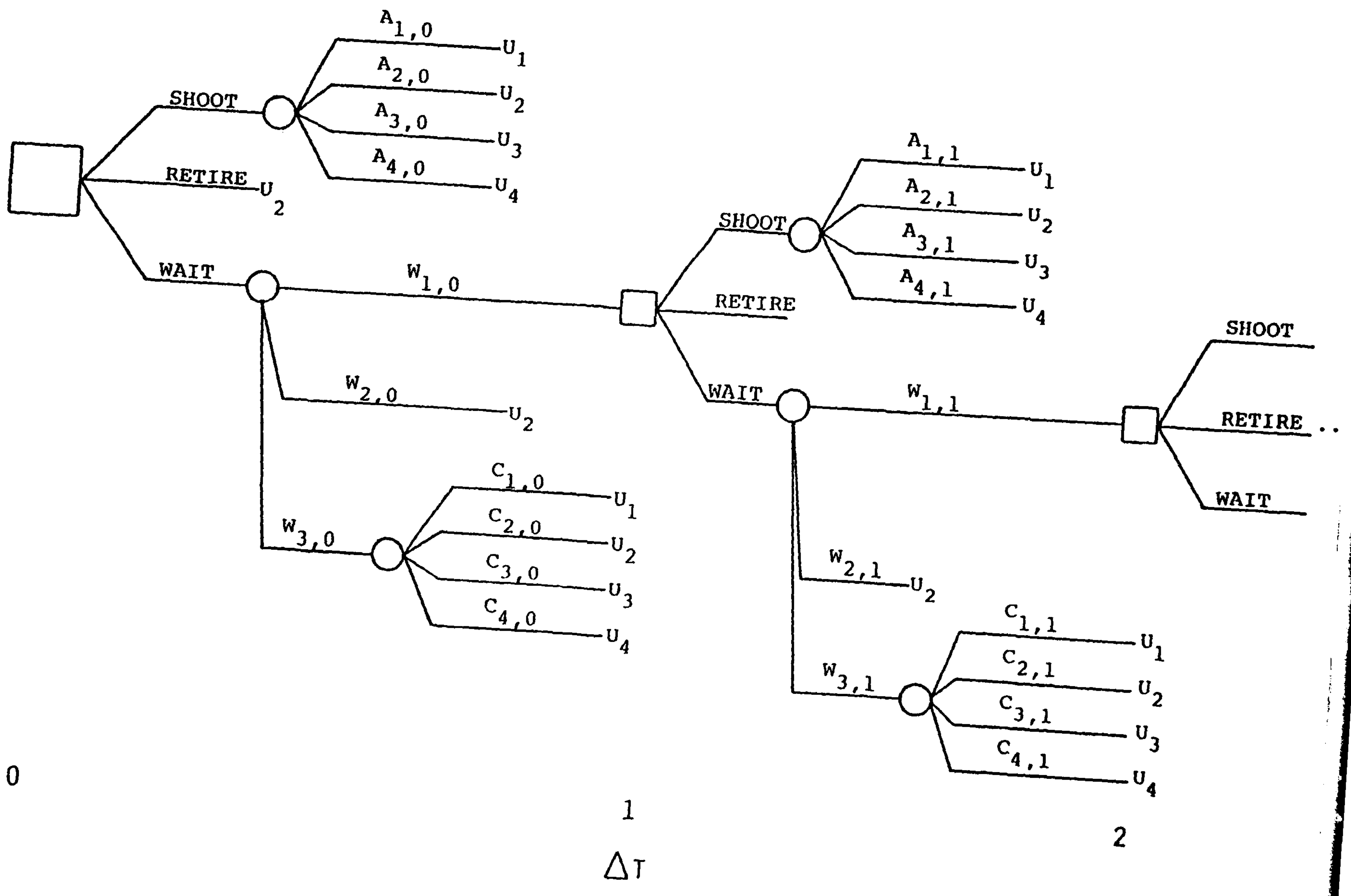
U_x = utility of outcome x

Values of x (in $A_{x,t}$, $C_{x,t}$, and U_x) refer to the possible combinations of killing/not killing and being killed/surviving: i.e., killing the target and surviving (x=1), not killing and surviving (x=2), killing and being killed (x=3), not killing and being killed (x=4). Values of y in $W_{y,t}$ refer to successful approach (y=1), loss of contact (y=2), and counterdetection (y=3). We designate the strategy of continuing approach up to time t and then attacking as S_t. Strategy S_1 will be used for illustrative purposes; generalization should be obvious.

Aggregated probabilities displayed by the attack planning aid are constructed from the above inputs. Two simple rules are involved: (1) The probability of a path through the tree is the product of probabilities for the component events. (2) The probability of an event is the sum of probabilities for different ways it can happen. Probabilities for ultimate objectives (killing and surviving), given strategy S_1, include all possible ways those events could occur, whether during approach or attack:

$$P(KILL|S_1) = W_{1,0}(A_{1,1} + A_{3,1}) + W_{3,0}(C_{1,0} + C_{3,0})$$

Figure B-2. Probability and Utility Inputs for Decision Tree



$$P(\text{SURVIVE}|S_1) = W_{1,0}(A_{1,1} + A_{2,1}) + W_{2,0} + W_{3,0}(C_{1,0} + C_{2,0}).$$

B.2.2 Assessing utility. The value of a target relative to own ship can be represented in two equivalent forms: (1) a graph of "target importance," arbitrarily assigning own ship a value of 100; and (2) an assessment of the "least acceptable" odds of killing a particular target (and surviving) versus being killed (and not killing the target) - i.e., the odds which would be just good enough to make an engagement with that target worthwhile, assuming that only these two extreme outcomes were possible.

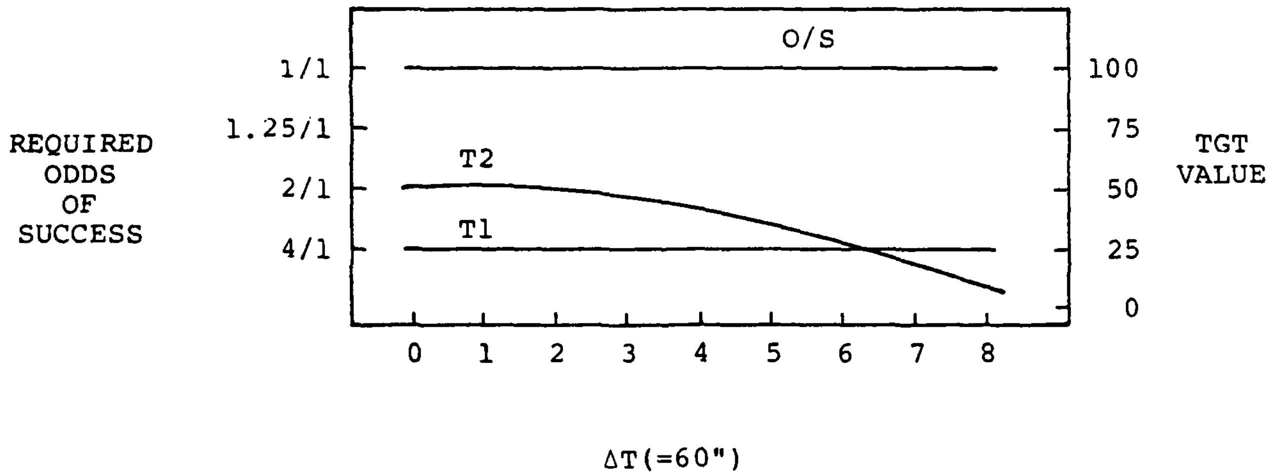
Figure B-3 illustrates the "target values" display obtained through the Planning Module. Value is a function of time, since the importance of destroying a threat will often depend very dramatically on when (i.e., how soon) it is destroyed. These values may be adjusted by the Commander through the Adjust Module.

Why is the value of a target associated with the lowest acceptable odds of success in an engagement with that target? In specifying such odds, the Commander in effect states a probability P such that he is indifferent between (i) leaving the scene and (ii) an engagement in which his chance of killing and surviving is P, and of being killed and not killing is 1-P. We assume that his degree of preference for the latter is represented by its expected utility: $PU_1 + (1-P)U_4$. When he regards the two situations as equally desireable,

$$PU_1 + (1-P)U_4 = U_2.$$

We can arbitrarily select an origin and scale unit, so we let $U_2 = 0$ (the status quo) and $U_4 = -100$ (the loss of own ship). Then we solve for U_1 (killing and surviving):

Figure B-3. Planning Module Display
of Target Values



$$U_1 = 100 \left(\frac{1-P}{P}\right).$$

The value of the target relative to own ship ($U_1/100$) is thus the reciprocal of the least acceptable odds.

In order to assess U_3 we make an important assumption: that the values involved in killing and surviving contribute independently to overall utility, i.e., it is equally desireable to kill the foe whether or not one survives oneself. The utility of killing and being killed is then the sum of component utilities:

$$U_3 = U_1 + U_4 = 100 \left(\frac{1-2P}{P}\right).$$

B.2.3 Evaluating action. The attack planning aid provides a figure of merit for each time of fire strategy, S_n, in the form of its expected utility. If we let P_x represent the probability of outcome x, given S_n, we have:

$$U(S_n) = P_1U_1 + P_2U_2 + P_3U_3 + P_4U_4$$

This expression can be simplified. Exploiting the fact that $U_2 = 0$ and $U_3 = U_1 + U_4$, we get:

$$\begin{aligned} U(S_n) &= P_1U_1 + P_3(U_1 + U_4) + P_4U_4 \\ &= (P_1 + P_3)U_1 + (P_3 + P_4)U_4 \\ &= P(\text{KILL})U_1 + [1-P(\text{SURVIVE})]U_4. \end{aligned}$$

An additive utility structure implies that the probabilities of joint events (e.g., KILL + SURVIVE) are irrelevant in evaluating strategies for attack. Hence, the attack planning aid provides the marginal probabilities of KILL and of SURVIVE and ignores the complication of likely non-independence between the two events.

APPENDIX C

DECISION PROCESSES OF SUBMARINE COMMANDERS

Early in the design process of the prototype aid, data regarding individual patterns in the use of information was gathered from a group of four former submarine Commanding Officers or Executive Officers. A written questionnaire presented to the four officers described a realistic scenario, involving several approach and attack situations varying in the number of targets or friendly contacts, degree of threat, and time pressure. At each of a number of break points in the scenario, the officers separately answered questions regarding: the information currently available on board the submarine which they would seek, the source from which they would seek it, the combat decisions that depended on the information, the way the information would affect those decisions, and the larger objectives of the decision.

The questions were designed to focus not only on current patterns of information use, but also on the decision-making processes within which that information plays a role.

Section C.1 contains the portion of the scenario used in the data analysis. Section C.2 gives the questions answered by the officers at each indicated break in the scenario. Section C.3 summarizes some of the data upon which conclusions noted in Section 4.2 were based.

C.1 Submarine Scenario (Relevant Excerpts)

Situation (t=0): You are the commanding officer of a 688 class SSN conducting independent operations in the northern Norwegian sea. A state of war has existed between the U.S. and the U.S.S.R. for the past three days and several ships have been sunk by each side. A nuclear weapon release message has not been received. The next submarine broadcast is scheduled to occur in forty minutes. The time is 1700 local, the month is June. The day was clear with sea state 3.

You have not made contact with the enemy since war was declared and have a full load of weapons. Patrol orders prioritize your targets in descending order as SSBNs, Kiev, SSNs, other warships, Soviet merships. NATO allies, except UK, have not declared war on the Soviets. Warsaw Pact warships are not be attacked. There is at least one British SSN conducting independent operations in the northern Norwegian Sea and a U.S. SSN has been reported enroute to CONUS, having completed a patrol in Barents.

. . .

Situation (t=10): You have evaded to the northwest and hold no sonar or ESM contacts. Own ship is not damaged. Sonar reports possible submarine bearing 015^{o}R, closing.

(Answer questions for t=10.)

Situation (t=11): Contact classified as submerged submarine. Bearing is drifting slowly to the right. Deep bow aspect, no turn count. Sonar estimates range as 6Kyds. Range of the day for Soviet Type III nuclear submarine doing 10 kts. is 11K yds.

(Answer questions for t=11.)

Situation (t=12): Situation is t=11 + 3 minutes. Lost sonar contact.

(Answer questions for t=12.)

Situation (t=13): Situation is t=12 + 5 minutes. Sonar has regained contact on the submerged submarine, B-020° T, range estimated as 9K yds. and closing. Sonar now reports contact on a possible second submerged submarine approximately 4K yds. behind the first.

(Answer questions for t=13.)

Situation (t=14): Sonar contacts located approximately as follows:

S1: B-045°T, C-210°T, Sonar Range - 5000 yds., Plot R - 8000 yds., F/C R - 6000 yds.

S2: B-042°T, appears to be sinuating between courses 260° and 170°, Range from plot = S1 + 3K yds.

Sonar reports a UQC transmission from S2. Clear voice, in Russian.

(Answer questions for t=14.)

Situation (t=15): New sonar contact (S3). Submerged submarine, B-350°T, closing.

(Answer questions for t=15.)

Situation (t=16): Bearing drift S1 & S2 is right 2°/minute. S2 changing course to right, AOB P-5° increasing. S1 has responded to UQC transmission from S2.

S3 bearing drift is left. Classification by sonar is British SSN running very deep.

(Answer questions for t=16.)

C.2 Instructions

The officers were provided with blank answer sheets divided into five columns, to be completed according to the following instructions after each segment of the scenario:

(1) What information would you seek at this time? Please be as specific as possible: For example, if you specifically want MATE, Ekelund, and geo plot range estimates, list all three (not just "range). But if you do want a "best range" estimate (e.g., from the XO), say so. Please list the information in the order in which you would seek it.

(2) Use the second column to describe the source which you would use to get the information: For example, list the display or plot if you would visually observe it yourself; if you would request the information from other personnel, list plotters, operators, or the FCC.

The next three questions concern why you want the information:

(3) In the third column, list the possible combat actions, preparations, or plans that depend on the information (e.g., withdrawal, weapon selection, target selection, maneuvers, time of fire, sensor selection, countermeasures).

(4) In the fourth column, discuss how your choices would be influenced by what you could learn from the information: e.g., "If escort is within X yards, it becomes the first target."

(5) In the fifth column, give the broad objectives you would have in taking the action (e.g., safety of own ship).

A second answer sheet, divided into two columns, was provided with the following instructions:

> There may be some combat actions which you would definitely take, regardless of any further information. If so, please list these and give your objectives in taking them.

C.3 Results

Figure C-1 indicates the major objectives referred to by each officer in each segment of the scenario, in answer to question (5). Figure C-2 describes the pattern of information search shown by each officer in each segment, as indicated by answers to questions (1) and (2).

Pronounced individual differences were observed both in decision making and information search:

- Level of aggregation of objectives: Among the larger objectives referred to, there was a fairly small set at the highest level: killing targets, prioritizing targets, preserving own ship, and avoiding harm to a friendly contact. However, there was variation both

Figure C-1. Objectives in Decision Making

Scenario Segment	Officers 1	2	3	4
10	K,S	(K)	S(K)	K,(K),(F)
11	K,Cn,S	K,(K),Cn	K,S	K,F,(F)
12	K,CD,Ct	K,(K),Ct	Ct	K,Ct
13	K,V	K,V,CD,(CD)	K,S,V	K,F
14	K,V	K,V,CD	K,S,CD	K,(K)
15	S,CD	K,(K),CD	K,S	K,F
16	K,S,F	S,F	K,S,CD,F	K,F

V = prioritize targets

K = kill target

(K) = achieve firing position/move within weapon range/open torpedo tube doors

S = own ship safety

CD = avoid counterdetection

(CD) = watch for target maneuvers (as a CD clue)

Cn = avoid collision

Ct = re-establish contact

F = avoid harm to friendly

(F) = classification (to identify friendly)

Figure C-2. Patterns of Information Search

Scenario Segment	Officers 1	2	3	4
10	A_4	$B_3B_2B_2C_1$	C_7	C_3
11	C_4	$B_3C_1B_3$	C_3	A_2
12	$A_2B_2C_1$	C_2	C_2	C_2
13	A_2	B_4C_3	$C_3B_2B_2C_1$	A_2
14	A_2	C_1	$C_4B_3C_1$	A_2C_1
15	B_2	C_2	B_2C_4	A_2
16	A_4	-	$C_4B_3C_1$	B_2B_2
Items in each Class				
A	14	0	0	8
B	2	6	5	2
C	5	10	30	6
Total Items	21	16	35	16

An: Single source, n items
Bn: Single item, n sources
Cn: n requests for different items from different sources

among officers and among situations in the level of detail at which objectives were specified - ranging, for example, from killing a target, to achieving a desireable firing point position, to getting the target within weapon range, to opening the torpedo tube doors; or from preserving own ship, to avoiding counterdetection or collision (Figure C-1).

- Number of objectives simultaneously used. Officers 1 and 2 shifted focus between own ship safety and killing the target; Officer 3 appeared to balance the two throughout; Officer 4 went all out for target kill, never once referring explicitly to own ship survival; on the other hand, this officer was much more likely to stress avoiding harm to friendly platforms (Figure C-1).

- Cutoffs. Three of the four officers (1, 2, and 3) made decisions which were explicitly dependent on cutoffs: all three used maximum weapon range as a criterion for attack; one (Officer 3) used counterdetection range as a criterion for withdrawal.

- Attitude toward risk. In a multiple target context, three of the four officers sought to prioritize targets for attack. Of these, Officer 3 decided to go after both targets, while Officers 1 and 2 opted for one target only. Officer 4 did not prioritize targets and decided to go after both.

- Inferences about feasible actions. Officer 4 listed attack as a definite action in segments 10 and 13; Officer 3 chose to attack a bit later, in segments 11 and 14; Officer 2 ordered definite attack only in segment 14; Officer 1 listed "preparation" for attack (but not an unconditional attack) in segments 10 and 11.

- Amount of information. The total number of items requested (from data currently available on board the submarine) varied considerably: Officer 3 made 35 different requests; Officers 1, 2, and 4 made 21, 6, and 16, respectively (Figure C-2).

- Pattern of information search. Data request patterns fell into three categories: (A) asking for a number of items from a single source, (B) asking for the same item from a variety of sources, and (C) asking for separate items from separate sources. Officers 1 and 4 tended to organize information search by sources, favoring pattern (A). Officers 2 and 3 never used pattern (A) at all; they did, however, organize search by items (B), validating a given bit of data by checking several sources. The predominent pattern for these two officers, however, was to gather a large number of different items from different sources (C) (Figure C-2).

C.4 Discussion

It may be instructive to compare directly the two officers who used the least (4) and the most information (3), respectively. Officer 4 never explicitly considered own ship survival, focusing on target kill and on avoiding harm to friendlies. He decided to attack both targets quite early and without explicitly considering their values. He did not use cutoffs explicitly on any dimension. His requests for information tended to call for a number of items from a given source (a fast strategy) with little validation or sampling of different sources.

Officer 3, on the other hand, balanced killing and surviving throughout, using cutoffs on both dimensions. He did not consider friendlies until there was a definite friendly contact (although one was known to be in the area). He decided to attack both targets a bit later than Officer 4 and after explicitly prioritizing them. His information requests were organized by item, often asking for validation from several sources.

Officers 1 and 2 were intermediate in many respects. They each considered kill and survive together on occasions, but sometimes focused exclusively on kill; cutoffs were used only on weapon range. Friendlies were considered only after definite contact. Each decided, after prioritizing targets, to go after only one. Information requests were organized by source, for Officer 1, and by item by Officer 2.

We cannot prejudge which of these officers were "better" than others. It is not implausible that each would fight best if the style that suits him were facilitated. In any case, differences exist, and they can be identified by a relatively simple procedure.

APPENDIX D

ILLUSTRATIVE AID ENHANCEMENTS

Potential improvements and enhancements of the attack planning aid fall into three categories: the interface, prescriptive models, and basic functions.

D.1 Interface

The Planning Module might be enhanced, for example, by including:

- a dynamic display capability, so that users can roll possible events forward or backward in time;
- optional scale settings in the Planning Displays (including the representation of relatively important nearby contacts in PD-B as well as PD-A);
- optional representation of target histories, and optional use of ellipses and fans to indicate uncertainty about target location and motion;
- "scrolling" within the Data Base Options display, so that, if need be, quick access to a longer list of options will be possible.
- facilitation of individualized search strategies among current status items, e.g., by source or by item.

D.2 Prescriptive Models

The Planning function of the aid would be better served, for some users, if the aid itself could generate action alternatives. The generation process would be tailored to the user: both in the selection of the criteria that determine acceptable alternatives and in the specification of the temporal duration of the maneuvers to be evaluated.

The Validation function of the aid might be enhanced by providing explicit indices of the credibility of various output displays.

In matters pertaining more specifically to approach and attack, models for aggregating basic inputs need to be refined and tested (e.g., for forecasting the impact of approach maneuvers on localization accuracy), and the aid must become capable of evaluating more complex weapon-firing sequences against multiple targets. The essence of the planning aid, however, is not in these details; rather, it is in the provision of a framework within which a large number of models and basic inputs can be integrated in a way that closely reflects user needs. The planning aid might become the nucleus of a more general submarine information management system, encompassing other missions and scenarios.

D.3 Aid Modules

The Selection Module can itself become tailored to an individual user, by providing a default "Choice" list subject to his revision. Such a list might be based on the aid's model of previous selections by that user in similar circumstances.

Additional prescriptive prompts might be offered: e.g., to sound an alarm when the actual unfolding of events appears contrary to forecasts previously provided by the aid; to prompt the user when sources of information are contradictory or redundant; and so forth.

A quite important new module might focus on model structuring. The user could then examine and revise not only default values, but algorithms which are employed in the data base to aggregate basic inputs into higher level inferences.

Further progress in all these areas will come from intensive interaction with potential users, increasingly rigorous testing, and a continuing concern for the proper balance between personal and prescriptive values.

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